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User's Manual for Western Root Disease Model

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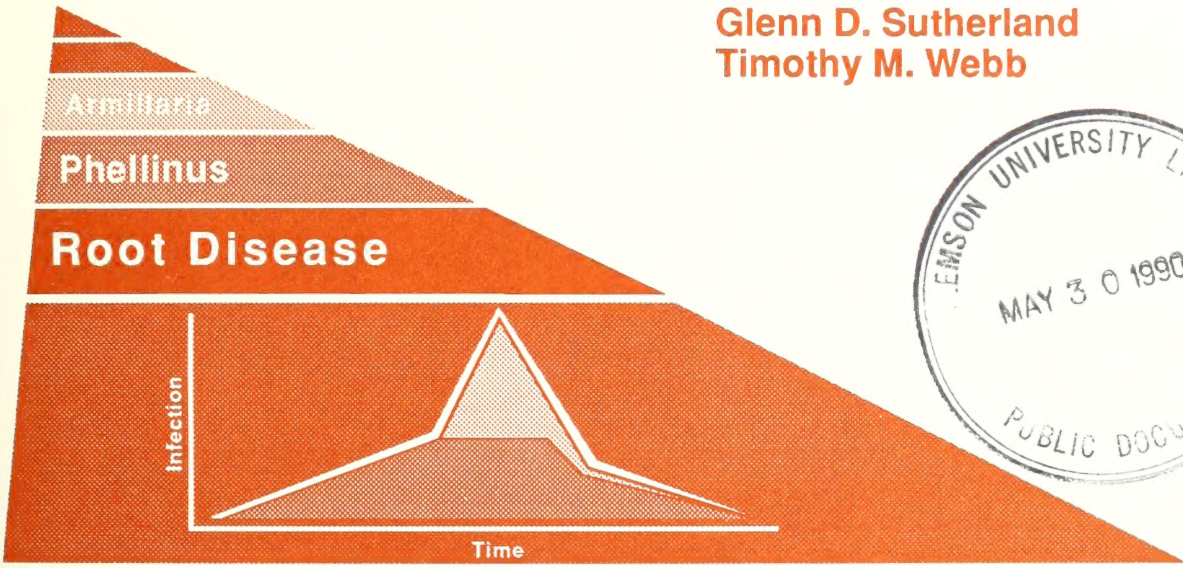

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RESEARCH SUMMARY

Effects of *Armillaria* spp. or *Phellinus weirii* on stand dynamics are represented by the Western Root Disease Model. This model, which operates in conjunction with the Prognosis Model for Stand Development, can be used to evaluate effects of a wide assortment of silvicultural practices, including stump removal for disease reduction. The model was developed through a series of workshops designed to elicit information about the disease process from many experts on the biology of the root diseases and their hosts. Forest land managers also participated in the workshops to provide their insight into the values and resources being affected.

This publication contains model applications, a brief description of how the model is formulated, and documentation of the keyword procedures for using the model.

ACKNOWLEDGMENTS

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CONTENTS

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INTRODUCTION

Tree root diseases pervade forested lands of the United States. Timber losses caused by root diseases have been estimated to average nearly 240 million cubic feet per year (Smith 1984). Root diseases typically originate from infected stumps of previous stands and spread to root systems of other trees in the immediate vicinity (Thies 1984; Wargo and Shaw 1985). The ability of these diseases to survive for many years in roots and stumps and to spread in stands throughout a rotation (possibly without early detection) imposes constraints on the management prescriptions available for regenerating stands (Bloomberg and others 1980). Management practices such as transplanting of trees, deep planting, partial cutting, fire prevention, or excessive removal of understory biomass may initiate or enhance the spread of one or more root diseases (Wargo 1980). Other practices, including use of disease-resistant tree species, trenching around infection centers, and careful cutting and commercial thinning methods, are known to reduce root disease impacts (Shaw and Roth 1978).

In response to managers' concerns for lack of information about the future development of diseased stands, a model was designed to predict the spread and impact of pathogenic *Armillaria* spp. or *Phellinus weirii* (Murr. [Gilbn.]) in mixed species, multiaged stands in the Western United States. The model was developed through a series of workshops in which the knowledge of many experts on the biology and management of root diseases was captured (Brookes 1985 and appendix I). With this information, and after several rounds of refinement, the model was produced; it currently operates in conjunction with the Prognosis Model for Stand Development. Details on the process of model development appear in Shaw and others (1985), Eav and Shaw (1987), and McNamee and others (1985).

The combined Prognosis/Root Disease Model can be used with existing forest inventories to evaluate possible outcomes of silvicultural prescriptions and root disease control activities for sites where root disease may influence stand development. Its uses include long-term planning for management of stands affected by root disease and for highlighting potential uncertainties and research needs for better understanding of root disease dynamics and effects.

To model effects of silviculture on root-disease organisms, and their effects on stand dynamics, requires a model of stand development that can represent stands of mixed species and ages. Furthermore, the stand model should represent the species and sizes of regeneration that are expected to fill openings created by tree mortality. The Stand Prognosis Model described by Stage (1973) and Wykoff and others (1982) has these capabilities. In addition, it is extensively used for examining and evaluating alternative stand management practices in the Western United States. The Prognosis Model is intended to produce estimates of realizable yield. Growth statistics calculated by the model include the average effects of factors such as climatic variation, past management activities, and pest damage as they are applied to the individual tree classes that make up the stand. One or more "extensions" to the Prognosis Model must be used to explicitly include interactions

between the stand and events such as establishment of regenerating stands, pest outbreaks, and understory development.

At present, the Root Disease Model is linked to the Prognosis Model. Once during each of the Prognosis growth cycles, which span about 10 years of simulated time, the Root Disease Model calculates rates of spread of the disease and numbers of trees within diseased areas that become infected. Then reductions in growth and increases in mortality are passed to the Prognosis Model to be used in updating tree attributes. At the end of each cycle, a summary of disease conditions is produced, as well as the usual descriptions of stand volume, accretion, and mortality produced by the base Prognosis Model.

When the stand is primarily composed of conifer regeneration of less than 3 inches diameter at breast height (d.b.h.), the usual Prognosis cycles are too long to capture the rapid dynamics of the disease process. In this case, a "miniature" version of the Root Disease Model is invoked with shorter time steps. This submodel is termed the "Carryover Model" because it serves to bridge the gap in modeling the transition from a mature stand to the reestablished stand at time of root closure.

Ecological Scope

The pathogens covered by this model, pathogenic *Armillaria* spp. and *P. weirii*, are widely distributed in forests of Western North America (fig. 1). Where these distributions overlap with the area covered by an existing variant of the Prognosis Model (fig. 1), the Root Disease Model can be used. However, when used with variants for which the regeneration establishment component (Ferguson and Crookston 1984) has not been implemented, projections will not include natural regeneration. When the stand is cut, the user must simulate regeneration through some sort of planting. In this manual, the examples will be based on the Inland Empire variant, which has a regeneration establishment component.

In addition to effects of pathogenic *Armillaria* spp. or *P. weirii*, the model includes interactions with damage caused by windthrow of trees in the stand and with three types of bark beetles. The bark beetle types are defined by their role in the dynamics of the root disease process. The three types are (1) dependent only on the density of susceptible stems, (2) dependent upon windfallen stems as refugia for the beetle population, and (3) dependent upon stems infected by root disease.

Management Actions Represented

The model can evaluate both direct control of root disease and a wide variety of silvicultural treatments, which may have indirect effects on the course of the disease.

Direct Control of Root Disease—The Root Disease Model implements only one management action specifically used for control of root disease, that of removal of inoculum by "pushing" infected stumps and their root systems (or by fumigation). This option can be requested in a specific year, with a factor specifying the efficiency with which roots are removed and the minimum dead tree/stump diameter for removal. This practice is an accepted management alternative in certain stands but should not be considered as feasible in all cases. A pathologist should be consulted to evaluate the possibility of using this option rather than selecting a resistant species, as described below.

Silvicultural Treatment—The silvicultural options available with the Prognosis Model can also be invoked to analyze alternative methods for indirect control of root disease. Regeneration systems to be simulated can span the full range from single-tree selection to clearcutting. In addition to the harvest of existing trees, new stands can be introduced following site preparation by natural regeneration or by planting. Of these, modification of species composition of regenerated stands through planting or choice of regeneration systems is the most effective means of avoiding root disease problems.

Figure 1—Locations covered by Prognosis variants. Shading indicates where either *Armillaria* spp. or *Phellinus weirii* is considered to be a management problem.

Data Required

The model is designed to start with sample inventories of actual stands. For example, the compartment examination procedure described by Stage and Alley (1972) and in USDA Forest Service Handbook 2409.21h R1 (1986) can supply the necessary stand data if augmented to include stumps infected with root disease.

In addition to the customary tree size attributes, the model uses information on the frequency of tree infection by root disease. This value can be compiled by the model from disease status codes of the individual sample trees or supplied by the user from an overall estimate based on an independent sample of the stand. The Root Disease Model also uses data on the area of the stand and the sizes and distribution of diseased centers to initiate the simulation. The model can start from bare ground by invoking the regeneration establishment component or from the description of the existing stand contained in the list of trees sampled in the inventory. Proportions of trees infected and proportions of roots infected within diseased areas can be supplied in the aggregate or by specifying disease status of each tree in the sample inventory.

APPLICATIONS IN PLANNING AND MANAGEMENT

The Root Disease Model is potentially an important pest model. Root diseases affect a significant area of the West, more than 3 million acres in northern Idaho and western Montana alone (Smith 1984). *Phellinus weirii* and *Armillaria* spp. which are represented in this model are the major pathogens in those States (James and others 1984) and in Oregon and Washington (Hadfield and others 1986). In addition, effects of *Annosus* root disease may be approximated by making changes in the parameters through use of the keywords of this model (Shaw and others 1989).

Root diseases strongly influence stand prescriptions. Stand losses can exceed 50 percent or more at rotation age. Therefore, projections of stand volumes that do not account for disease effects can be greatly inflated. Even so, short-term effects can be subtle and easily underestimated. The loss of only a few trees per acre a year, many of which are salvaged for firewood or fall down from decay in a relatively short time, makes it difficult to recognize the magnitude of the problem. Silviculturists can learn from gaming with the model how past practices may have exacerbated the root disease problem and how prescribed treatments may reduce future losses.

The Root Disease Model may also be useful because the disease process is predictable. Although the model is still relatively new and untested, and many aspects of disease behavior are incompletely known, root disease, once established in a stand, is persistent. Tree killing and disease center enlargement continue at a relatively slow but predictable rate compared with certain other pests that are sporadic and unpredictable in occurrence and intensity. Empirical data to accurately assess these relationships are scarce. Therefore, outputs from the model should be used in a qualitative sense to evaluate alternative management prescriptions rather than as a precise quantitative estimator of future root disease impacts. However, output from the model will provide a "best guess" based on expert opinion and is likely to be more realistic than estimates by less experienced personnel. How important these best guesses are has been explored through model sensitivity analyses (McNamee and Sutherland 1986).

Stand Level

Because the model predicts stand growth and yield under different stand treatments and disease intensities, the results can be used to formulate stand prescriptions that will meet specified objectives and to communicate the treatment effects to interdisciplinary team members, line officers, and others. The model may be used at any stage of stand development. However, it may be most valuable for planning the regeneration phase because the greatest opportunity to influence root disease occurs at that time.

The most frequent approach to management of root disease problems in timber stands is regeneration to site-suited tree species that are disease tolerant. The model can be used to compare the effects of variations of this approach, as well as others. For example, the following options may be considered:

1. A clearcut, seed-tree cut, or shelterwood cut followed by regenerating to disease-tolerant species, or a mixed stand with a predominance of tolerant species.
2. Overstory removal from an understory that might be disease susceptible, tolerant, or a mixture of the two.
3. A clearcut and stump removal, followed by planting of a disease-susceptible but otherwise preferred species.
4. No treatment, or a deferred treatment.

We recommend that two other simulations be included even if those actions are not contemplated because they provide baselines against which other treatments can be compared:

1. Harvest without stump treatment, followed by natural regeneration, even if it consists of susceptible species. Simulate with the Root Disease Model operating.
2. Harvest, followed by planting of preferred species, ignoring root disease considerations. Simulate without the Root Disease Model operating.

In precommercial stands the model also may be used to evaluate effects of different treatment alternatives. Treatment options at this phase might include precommercial thinning, using various leave tree species and spacing rules, deferred or no treatment, and destroying the existing stand to replace with a disease-tolerant species.

Forest Level

Long-term planning for sustained yield requires that the yield potential of existing stands be estimated unbiasedly. All too often, inventories of young stands do not adequately describe the root-disease status. As a consequence, their future contribution to forest yield is seriously overestimated if they consist of susceptible species growing on infested sites. In the judgment of some managers, omission of pest effects may have resulted in plans that, in reality, are infeasible.

Representation of root disease impacts on long-term plans requires three elements:

1. An inventory that identifies those sites on which root disease can be expected to cause losses. Guides for classifying sites with respect to the risk of loss from root disease could be developed for some areas from information in Byler and others (in press), McDonald and others (1987), Williams and Marsden (1982).
2. A model such as this one for representing effects of proposed management activities on future yields that includes interactions between tree growth and mortality and the dynamics of the root pathogens.
3. A structure for a planning model that permits site-specific yield forecasts to be used in developing solutions to the yield scheduling problem. Stage and others (1986) suggested one such structure.

To be effective, all of the yield-estimating procedures used in a given planning solution should include pest effects. Otherwise, the solution would favor harvesting of stands with higher potential yield, even if those stands are, in their own right, also susceptible to damage by various pests.

Multistand Analysis

The model has the potential for describing disease effects and evaluating alternative treatment strategies at intermediate planning levels.

A strategy for reducing pest-caused losses for compartments or entire watersheds is to select high-risk stands for immediate harvest and defer treatment in low-risk stands. Root Disease Model simulations on stands of different ages, species composition, stocking, and disease condition could be used to set harvesting priority. Thus, mortality that would otherwise occur in high-loss stands would be captured and the growth potential of the site realized by regenerating to species tolerant of disease.

The Root Disease Model also has potential at the multistand level when implementing forest plans. The desired future vegetative conditions to achieve the mix of products and values identified in the plans remain to be specified. By projecting growth and development of many stands in an analysis area, effects of root disease and various treatments can be displayed. Stands can be scheduled for treatment in a sequence that best meets the management objectives. For example, treatments could provide a mix of stands at different successional stages, spaced in a manner that would meet visual management objectives, provide for big game hiding cover (Canfield and others 1986), thermal cover, and browse (Moeur 1985) yet provide a flow of timber products as well.

Crow Creek Stand— An Example

To illustrate use of this modeling system, we will develop a simulation for a stand in the Crow Creek drainage on the Lolo National Forest. This 51-acre stand is about 130 years of age, growing on a *Thuja*/*Clintonia* habitat type at an elevation of 3,300 feet. When the stand was examined in 1983, it consisted of grand fir, larch, redcedar, and Douglas-fir. *Armillaria* occurred on two of the seven inventory plots. One possible scenario for management of this stand is to harvest the existing trees

in 2003, burn the slash, and plant larch. On this productive habitat, there will also be substantial natural regeneration, but largely comprising grand fir and Douglas-fir, which, in this habitat, are susceptible to damage from root rot. Therefore, a cleaning at age 10 favoring larch will remove most of the natural regeneration. The Prognosis Model keywords and data representing the Crow Creek inventory are listed in table 1. Portions of this input that contain information specific to the Root Disease Model are shaded.

Table 1—Keywords for the Root Disease and the Prognosis Models as they occurred in the Prognosis Model input file for a stand in Crow Creek on the Lolo National Forest

```
STDIDENT
164581202025 CROW CREEK DATA-R1-ROOT DISEASE
COMMENT
    - RRSETB - TEST ROOT DISEASE MODEL
    - TYPE OF STAND - INVENTORY
    - ROOT DISEASE - ARMILLARIA
    - 7 PLOTS, 2 WITH RD
    - RANDOM CENTERS
END
TREELIST          1.
DESIGN         40.0      300.0        5.0        7.0        0.0        1.0
STDINFO        16.0      530.0      130.0        2.0        1.0       33.0
INVYEAR      1983.0
GROWTH          0.0        5.0
NUMCYCLE       20.0
NOTRIPLE
THINDBH      2003.0        1.0       99.0        1.0
TIMEINT         3.0        5.0
TIMEINT         4.0        5.0
TIMEINT         5.0        5.0
TIMEINT         6.0        5.0
TIMEINT         7.0        5.0
TIMEINT        20.0        5.0
ESTAB        2003.0
BURNPREP     2004.0        80.
PLANT        2005.0        2.0      500.0       80.0
TALLYONE     2007.0
TALLYTWO     2012.0
RESETAGE     2005.         0.0
HTADJ        2005.0        2.0        1.5
END
SPECPREF     2008.0        2.0       -2.0
THINBTA      2013.0     1000.0
RRIN
SAREA          51.0
PLREAD
   1
   5
-999
RRTYPE          1.0
RRINIT          0.0        3.0                              0.4      21.00
RRTREIN
STREAD
   3  25.0  10.0
   4  15.0  25.0
   3   5.0 100.0
-999
CARRY           1.0        4.0       0.02
SPREAD          1.0
PSTUMP       2003.0        0.8        3.0
RRJUMP          1.0
RSEED       11188.0
RRDOUT
END
```

(con.)

```
TREEFMT
(13X,I4,T1,I5,T28,F2.0,T25,I1,T33,A2,F3.1,F2.1,3X,F3.0,T43,F3.0,T54,
F2.0,T46,I1,T48,3(I2,I1),T22,I1,T22,I1)
TREEDATA        5.0
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1645812020252 001   20  0   0 13 ODF214 7 5210752611  0   02700 0 0    0000
1645812020252 001   30  0   0 16 ODF184 0  010200610  0   00 00 0 0    0000
1645812020252 0011010  0   0 11 OGF 3310 26 1783611  0   01 00 0 0    0000
1645812020252 0011020  0   0 11 ODF  1 0 18  263611  0   01 00 0 0    0000
1645812020252 0011030  0   0 11 OGF  1 0 15  153611  0   01 00 0 0    0000
1645812020252 0011040  0   0 51 OGF  1 0 22  154611  0   00 00 0 0    0000
1645812020252 0011050  0   0101 ODF  1 0 31  055611  0   00 00 0 0    0000
1645812020252 0011060  0   0 74 ODF  1 0 31  055902611   00 00 0 0    0000
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1645812020252 002   30  0   0 11 OGF 5711 37 5073  0  0   01 00 0 0    0000
1645812020252 002   40  0   0 12 ODF 59 3 45 3844  0  0   00 00 0 0    0000
1645812020252 0021010  0   0 11 OGF  1 0 23  254  0  0   01 00 0 0    0000
1645812020252 0021020  0   0201 OGF  1 0 22  154  0  0   00 00 0 0    0000
1645812020252 0021030  0   0 54 OGF  1 0 22  054  0  0   00 00 0 0    0000
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1645812020252 003   20  0   0 12 OL  57 9 53 5453601  0   01 00 0 0    0000
1645812020252 003   30  0   0 12 OLP 83 4 57 6733601  0   01 00 0 0    0000
1645812020252 0031010  0   0 11 OC   9 0 25  774601  0   01 00 0 0    0000
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1645812020252 0041010  0   0 14 OLP 39 3 43 5233902  0   02 00 0 0    0000
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```

(con.)

Table 1 (Con.)

```
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1645812020252 007   80  0   0 12 OC  31715 5011053   0   0   00  00 0 0       0000
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             -999
PROCESS
STOP
```

PREPARING A SIMULATION

The Root Disease Model is controlled, and its parameter values modified, through 27 keywords similar in structure and use to those in the Prognosis keyword system (Wykoff and others 1982). A submittal system that interactively assists the user to prepare the necessary sequence of keywords and tree data has been a useful adjunct to the Prognosis Model. A system for users of pest models, including the Western Root Disease Model, is fully integrated with the above system for growth and yield models (Gladden 1989; Sleavin 1989).

The Keyword System

Root Disease Model keywords allow users to:

1. Control program execution, including the nature of root disease processes simulated, and the interaction with other agents.
2. Describe initial conditions of the stand and its disease status.
3. Specify management prescriptions to be invoked.
4. Change critical factors, particularly those that can be habitat-specific or dependent on the source of new trees; and to assume static rates and probabilities for one or more of the processes governing root disease dynamics.
5. Investigate effects of bark beetles and windthrow on root disease dynamics.

The Root Disease Model is invoked by inserting a sequence of root-disease keywords into the sequence of keywords for a normal Prognosis simulation. These keywords may be inserted by editing a Prognosis runstream or by using a submittal system such as that described in the next section.

The first keyword in the Root Disease Model control section is always RRIN, and the list is always terminated by the keyword END. Root Disease keywords must be kept together as a discrete unit. Also, they must not be inserted into the middle of another model extension list of keywords (such as the regeneration establishment model keywords). As in the Prognosis Model, all keywords are left justified in the first 10 characters of the record. If required, the next six 10-character fields (the parameter fields) may be used to add numeric data. Numeric data should include a decimal point or be right-justified in the field.

Users of the Forest Service Growth and Yield Submittal System on the Data General (Sleavin 1989) can generate the Western Root Disease Model keywords by choosing the keyword "PEST" from the Main Keyword Entry Screen. When the keyword PEST is selected, the Pest Model Submittal System (Gladden 1989) is invoked. A menu of pest models available for the particular variant of Prognosis is the first screen displayed. From this menu of pest models, the user can select the "WESTERN ROOT DISEASE MODEL."

Once the Western Root Disease Model is invoked, the system displays this model's Main Keyword Entry Screen, which gives the user the following options:

1. Program Execution Options
2. Root Disease Inventory Options
3. Root Disease Management Options
4. Model Modification Options
5. Other Agent Options
6. Process All Root Disease Keyword Groups
7. Add, Replace, or Delete a Keyword
8. Display All Entered Keywords
9. Exit Main Keyword Entry Screen

The last three of these options are shared by several other pest models served by the same submittal system. With the selection of a group, the system displays the appropriate keywords in that group for processing.

The main advantage of the submittal system is that it lets the user run the model without having to be concerned with formats of keyword parameters. In addition, users do not have to learn job control language and file assignment protocol for the USDA National Computer Center's computers in Fort Collins, CO, where the model resides. Formatting of keywords and all necessary job control language statements are handled by the submittal system. Furthermore, the system performs some checks for values entered to prevent logical errors and ensure that mandatory keywords are present in the keyword file.

Controlling Program Execution

The keywords that control program execution accomplish three general tasks. The RRIN and END keywords signal the beginning and ending of root disease-specific keywords. COMMENT is used to print out a more detailed description of the run. Finally, the RRDOUT and RRECHO keywords serve to control the format and amount of output generated by the model. The keywords for both the Root Disease Model and Prognosis are written to an output file.

RRIN — The RRIN keyword is actually a Prognosis model keyword, signifying that the Root Disease Model is to be called. All following keywords, up to the END keyword, must be Root Disease Model keywords. Use of this keyword with the Root Disease Model is mandatory.

COMMENT — This allows the user to enter a comment describing the root disease scenario being specified. This comment, entered on supplemental records, can be as many lines as the user wishes and is printed as part of the regular output provided by the Root Disease Model. The final supplemental record must contain "END." If such a supplemental record is not provided, keywords that follow will be assumed to be part of the comment and not processed as keywords. This "END" is not to be mistaken for the END keyword that signifies the end of the root disease keywords.

Supplemental Records

The supplemental records that follow this keyword form the comment statement.

DEFAULT: No comment statement is provided.

RRDOUT — This keyword allows the user to get more detailed output from the Root Disease Model. More detailed output will be provided if the keyword is present.

Field 1: This field contains the file reference number on which the detailed output will be provided. If this field is blank, a value of 22 is assumed.

DEFAULT: No detailed output is provided. If the keyword is provided with blank fields, detailed output will be directed to file-reference number 22.

RRECHO — The summary output is usually written with headers at the beginning that describe the output. Often, a user wishes to make a series of simulation runs and store the output from all scenarios for later analysis. In this case, headers are not needed. The RRECHO keyword allows the user to print out a machine-readable root disease summary table with no headings, in addition to the normal root disease summary output.

Field 1: This field contains the file reference number on which the machine-readable summary output is to be written. The default value is 24.

DEFAULT: No machine-readable output is printed.

END This keyword signifies the end of the root disease keywords. No field entries are needed. This keyword *must* be provided. Otherwise, all Prognosis Model keywords that may follow will be taken as invalid Root Disease keywords and not processed.

Entering Inventory Data

The Prognosis Model is initialized with a list of individual tree and stand characteristics from stand inventories. Sample-tree data are used in conjunction with a description of the sampling design to estimate stand statistics such as volume per unit area. Other information about sample trees (total height, crown ratio, past growth increment) and about the site (slope, aspect, elevation, and habitat type) may be optionally provided by the user.

The Root Disease Model is capable of defining initial root disease conditions using stand examination data that describe the root disease status of sample trees and stumps. The model summarizes number of infected and uninfected trees per acre inside root disease areas, number of trees per acre outside of root diseased areas (all of which are assumed to be noninfected), and the number, size, and type of stumps. When stand examination data do not include the disease status of sample trees, initial root disease conditions may be found through variables entered by user-supplied keywords, which define how the initial conditions for root disease are to be specified.

The RRTYPE keyword specifies the fungal species causing root disease in the stand. The model will not simulate infection by *Armillaria* spp. and *P. weirii* in the same stand at the same time. RRINIT indicates the configuration of the root disease centers within the stand and may also be used to enter the number of diseased and healthy trees within centers.

Alternatively, the disease status of individual trees may be entered for each sample tree as part of the information on the input tree list if the RRTREIN keyword is present. If the stand being represented with the RRTREIN keyword has been inventoried with a number of subplots, the numbers identifying those subplots that are in disease centers are entered with the PLREAD keyword. In addition, the total area of the stand is given by the SAREA keyword; this information is used to calculate tree densities inside root disease centers. If stumps are inventoried in the stand, then the STREAD keyword can be used to initialize the number and attributes of infected stumps.

Many Root Disease Model keywords require a tree species to be designated. An index between 1 and 11 identifies the conifers represented in the Prognosis Model. Conifer species indicated by the index may vary with different geographic variants of Prognosis. For the Inland Empire variant, the index corresponds to the following species:

1. Western white pine (*Pinus monticola*)
2. Western larch (*Larix occidentalis*)
3. Douglas-fir (*Pseudotsuga menziesii*)
4. Grand fir (*Abies grandis*)
5. Western hemlock (*Tsuga heterophylla*)
6. Western redcedar (*Thuja plicata*)
7. Lodgepole pine (*Pinus contorta*)
8. Engelmann spruce (*Picea engelmannii*)
9. Subalpine fir (*Abies lasiocarpa*)
10. Ponderosa pine (*Pinus ponderosa*)
11. Mountain hemlock (*Tsuga mertensiana*)

Indices for other Prognosis Model variants are in the documentation of those variants.

RRTYPE: This keyword allows the user to specify the root disease type to be simulated.

Field 1: The value in this field should be a 1 or a 2. If it is 1, *Armillaria* is simulated. If it is 2, *P. weirii* is simulated. Any other value in field 1 will cause an error message to be printed and *Armillaria* will be simulated.

DEFAULT: *Armillaria* will be simulated.

SAREA This keyword defines the stand area to be simulated in the Root Disease Model and recalculates the dimensions of the stand as a square.

Field 1: This field contains the new stand area in acres that is to be simulated. A value in field 1 that is not positive will cause an error to be printed and the stand area to be set to 100 acres.

DEFAULT: The stand area is 100 acres.

We cannot overemphasize the importance of defining the stand area and root disease type to be simulated before other root disease conditions are defined. These two variables should be defined for the scenario before the conditions described with the other keywords can be meaningful.

If root disease is scattered throughout the stand, then one should consider starting the simulation with the area in root disease equal to stand area. However, when that option is used, or if spread has been sufficient to engulf the entire stand, spread-rate estimates become meaningless.

RRINIT This keyword indicates configuration of root disease centers. The user has two options. In the first, the user specifies the total area in root disease and the number of centers. Then, the model will randomly locate the root disease centers throughout the stand. Centers will be circles of equal size, calculated as the total area in root disease divided by the number of centers. The alternative is to provide a list of root disease centers with the X and Y coordinates of each center and its radius. If RRTREIN is not used, fields 3 and 4 of this keyword also provide information on the number of healthy and diseased trees within the root disease centers.

Field 1: This field specifies whether initial coordinates of root disease centers are to be assigned randomly or read in. If it has value = 0, root disease coordinates are chosen randomly. If it has value = 1, root disease center attributes are read in with supplemental records. The default value of 0 is used if no value is entered in this field.

Field 2: This field specifies the total number of root disease centers to be located in the stand. If attributes of root disease centers are to be read in (field 1 = 1), several supplemental records (equal to the value in field 2) are expected to follow. The number of centers cannot exceed 100. If field 2 exceeds 100, an error message is printed and the number of centers is set to 100.

Field 3: This field contains the number of infected trees per acre in the root disease centers. If no value is supplied, a default value of 50 percent of average stand density (trees per acre) will be used. If this value is to be obtained from the inventory tree list (indicated by the RRTREIN keyword), then the value in this field will be ignored.

Field 4: This field contains the number of uninfected trees per acre in the root disease centers. If no value is supplied, a default value of 50 percent of average stand density (trees per acre) will be used. If this value is to be obtained from the inventory tree list (indicated by the RRTREIN keyword), then the value in this field will be ignored.

Field 5: This field contains the average level of root infection on infected trees. It should be a number between 0 and 1 (which indicates 100 percent infection). All infected trees read in field 3 are given this infection level. The default value of 0.1 is used if no value is entered in this field.

Field 6: This field specifies the total acres in root disease and is only read if root disease centers are to be assigned randomly (field 1 = 0). In this case, the area of each root disease center is equal to field 6 divided by field 2.

Supplemental Records

Supplemental records are expected following this keyword if the root disease centers are to be read in (field 1 = 1). Each supplemental record contains all necessary information for one center and is read in with format 3F7.1: X-coordinate of the center in feet, Y-coordinate of the center in feet, and radius of the center in feet. An error will appear if either the X or Y coordinate of a center is outside the linear dimensions of the stand (assumed to be square) and the coordinate will be set to the linear dimension of the stand (on the edge of the stand). It is therefore important to define the total stand area with the SAREA keyword before using this keyword.

DEFAULT: Center locations assigned randomly, total center area is 25 percent of stand area, with 20 centers of equal size.

Fields 3 and 4 for the RRINIT keyword and the tree defect and damage codes entered on the individual-tree inventory data used in conjunction with the RRTREIN keyword provide the same kind of information to the model. However, the two alternatives may give somewhat different results during the first few periods of growth. When infection status is entered with RRINIT, all trees in the stand represented by a particular tree record in the sample are assumed to be divided between infected and uninfected in the same proportions. However, when status is indicated separately for each sample tree, differences in the infected proportions of the many sizes and species of trees in the stand are possible. Which alternative is more realistic depends on the adequacy of the sample of trees in the inventory input. For small samples, perhaps less than 40 trees, RRINIT may be better. With larger samples, the RRTREIN option should be more realistic.

RRTREIN This keyword is used when initial disease conditions are included in the attributes of individual trees in the list of trees. Disease conditions of the sampled trees are described by three pairs of descriptors. Any one of the three may contain the root disease condition of the tree. The remaining two can be used to describe other insect, disease, or damage symptoms. Although arbitrary, the usual ordering is by importance. The first variable in each pair identifies the presence of a particular damaging agent. The second variable describes the severity of the condition. Any tree less than 5 inches d.b.h. and with a severity of 1 is not considered as infected. Default values of these codes are taken from specifications in the Forest Service Handbook FSH 2409.21h R1 Field Instructions for Stand Examinations (1986).

Agent	Code	Severity	Code
Armillaria	61	Tree within 30 feet of tree with deteriorating crown or killed by root disease.	1
P. weirii	62	Pathogen or diagnostic symptoms detected.	2
		Crown deterioration	3

The tree class information used in the Root Disease Model corresponds to the tree history information used in the Prognosis Model (variable ITH). When the Root Disease Model is active, the tree class information should be read into the Prognosis Model variable ITH. Tree class codes 6 and 7 identify trees that have died 5 years ago or less. Tree class codes 8 and 9 represent trees that have died more than 5 years ago.

Stumps, in the context of the Root Disease Model, are cut stumps or trees that are dead and infected with root disease. For example, a tree with a tree class of 6 and a damage code of 61 would be classified and processed as an infected stump. Stumps can also be added to the Root Disease Model in another way when using the tree list information. Trees that were infected by root disease and cut in previous rotations are identified by entering a tree height of 1.5 for the Prognosis Model variable THT. These trees are classified and processed as stumps and then discarded. Finally, additional stumps can be added to the root disease model when using RRTREIN keyword by using the STREAD keyword. When the Root Disease Model is used with initial user-supplied information, stumps can only be added to the model using the STREAD keyword.

PLREAD This keyword, which is used only in conjunction with RRTREIN, indicates which subplots within the stand contain root disease. This keyword should be used when modeling a stand that contains both relatively large, identifiable areas of root disease and areas unaffected by root disease. Its absence, but with RRTREIN present, indicates that the stand is to be modeled as a single root disease center. No parameter fields are read in conjunction with this keyword. The user is, however, expected to provide supplemental records that contain the subplot identification of plots in diseased centers.

Supplemental Records

Each supplemental record should contain one number in I4 format. This is the diseased subplot number. A –999 entered at the end of the list of diseased subplot numbers indicates that all the disease

subplot information has been read. This supplemental record must be provided; otherwise, keywords that follow will be assumed to be part of the subplot list and not processed as proper keywords.

STREAD

This keyword is used to initialize stumps within the root diseased areas of the stand. A stump, in the context of the Root Disease Model, is defined as an infected tree that is killed by any means. The tree can be a stump formed by cutting, a dead standing tree, or a tree that has been snapped off by wind. The important attribute of these stumps is that they were formed by trees that were infected by root disease at the time of their death by whatever cause. These stumps will serve as inoculum sources from which infection will spread through the simulation. No parameter fields are read in conjunction with this keyword. However, the user is expected to provide supplemental records that contain necessary stump information.

Supplemental Records

Each supplemental record should contain three numbers in format I4,2F6.1. The first field contains the index of the tree species tabulated previously. Species identification is important because stumps of heartwood species are assumed to decay more slowly than stumps of nonheartwood species. Douglas-fir, all pines, western redcedar, and western larch are classified as heartwood species; the remainder are classified as nonheartwood species. The second field is the stump diameter in inches, taken at one foot above ground. The third field is the number of stumps of the given heartwood class and diameter. This number should be given as the total number of stumps of this type in the root diseased area, and not the number of stumps per acre. A –999 entered in the first four columns of the supplemental record indicates that all the stump list information has been read. This supplemental record must be provided; otherwise, keywords that follow will be assumed to be part of the stump list information and not processed as proper keywords.

When the RRINIT keyword is used and STREAD keyword omitted, the model assumes there are no stumps present. When the RRTREIN keyword is used, stump information can be entered into the model directly from the input tree list even though the STREAD keyword is omitted. Stump information may also be entered into the model from both the input tree list and the STREAD keyword when RRTREIN is used.

For our Crow Creek example, examination of aerial photos indicates that 21 of the 51 acres in the stand are in three root disease centers. Note that the proportion of infested area is greater than indicated by the proportion (2/7) of infested plots. Because the status of root disease was recorded for each tree in the inventory, the RRTREIN keyword will be used. However, because there are relatively few plots in the diseased portions of the stand, an additional list of infected stumps will be supplied by the STREAD keyword.

The Crow Creek data are similar to standard Forest Service Region 1 stand exam data. Tree damage codes are in columns 48-50, 51-53, and 54-56. Up to three damage types or agents can be recorded. The first two columns are the agent or cause, the last is the severity. When the data were taken the following were allowable root disease codes:

60 ROOT DISEASE

61 Shoestring root rot (*Armillaria* spp.)

62 Yellow laminated root rot (*P. weirii*)

63 Brown cubical rot (*Polyporous schweinitzii, Coniphora puteana*)

64 White rot (*Heterobasidion annosum, Poria subacida*)

65 Black stain root disease (*Verticicladiella* sp.)

Severity Codes:

1. Tree within a disease center or within 30 feet of a tree or stump that is symptomatic or killed by root disease.
2. Root disease confirmed by stain, decay, or other signs or symptoms.
3. Root disease crown symptoms.

Specifying Management Options

The only management action that is specific to root disease is pushing stumps, specified by the PSTUMP keyword. Although fumigation of stumps is a possibility for reducing inoculum, for the present, its effects can be approximated by varying the parameters of PSTUMP. Other silvicultural options that can influence the dynamics of root disease, such as species choices when planting or thinning, are invoked by using the options in the base Prognosis Model.

PSTUMP — This keyword simulates a stump-pushing event in a particular year of the rotation. Stump pushing can only occur once in a scenario.

- Field 1: The year in which stump pushing is to occur.
- Field 2: The stump-pushing efficiency. This is the proportion of stumps that will be removed by the stump-pushing activity. The default is an efficiency of 1.0. An error message will appear if the entry in field 2 is less than 0 or greater than 1, and the default will be retained.
- Field 3: The minimum stump diameter for stump pushing. All stumps of this diameter and greater will be removed with the efficiency provided in field 2. If left blank, the minimum stump d.b.h. is set to 0 inches and all stump sizes will be removed with the efficiency provided in field 2.

Interactions With Other Damaging Agents

Action of other agents in influencing mortality inside root disease centers is controlled by the BBTYPE1, BBTYPE2, BBTYPE3, and WINDTHR keywords. These keywords simply switch on the potential for a bark beetle or windthrow event to occur. The event will not occur before the specified cycle year and will not occur if conditions are inappropriate. Thus, a user could specify a cycle year of 1991 on the keyword line but not have the event occur until 2021 because conditions from 1991 to 2021 were not suitable for the event to occur. Each of the BBTYPE keywords uses an index of tree species in field 2.

BBTYPE1 — This keyword specifies a type 1 bark beetle event. Examples of type 1 bark beetles are mountain pine beetle (*Dendroctonus ponderosae*) on lodgepole pine and western pine beetle (*D. brevicomis*) on ponderosa pine. The user specifies a year and intensity to switch this other agent on. The type 1 bark beetle model is switched off after one outbreak has occurred.

- Field 1: This field specifies the earliest year that an outbreak can occur. This field must be specified, there is no default value for year.
- Field 2: This field specifies the tree species eligible for attack by the bark beetle and should be a number between 1 and

11, inclusive, which is the tree species index applicable to your variant of the Prognosis Model. If the field is left blank, the default is 7, which is lodgepole pine in the Inland Empire variant.

Field 3: This field specifies the minimum d.b.h. (in inches) of trees that will be considered eligible for attack by the bark beetle. The default is a d.b.h. of 8 inches.

Field 4: This field specifies the minimum density of eligible trees as specified by fields 2 and 3, which must be present before an outbreak can occur. The default density is 10 eligible trees per acre.

Field 5: This field specifies the mortality rate that will be applied to all eligible trees if an outbreak occurs. The default rate is 0.85 for all eligible trees.

BBTYPE2 This keyword specifies a type 2 bark beetle event. An example of type 2 bark beetle is Douglas-fir beetle (*D. pseudotsugae*) on Douglas-fir. The user specifies a year and intensity to switch on this agent. A type 2 bark beetle outbreak can occur only if a windthrow event of a sufficient size also occurs. An error message is printed if the BBTYPE2 keyword is provided without the WINDTHR keyword, although the WINDTHR keyword does not have to precede the BBTYPE2 keyword. The mortality of live trees is determined by the number of windfallen trees that are of the size and species specified as host for this bark beetle. The number of live trees killed by the bark beetle is only slightly fewer than the number of host trees wind-thrown. For example, if 12 Douglas-fir trees of the size specified were wind-thrown, then 11 more live trees could be attacked and killed by the beetle. This action is dependent on there being a sufficient number of eligible stems remaining after windthrow for bark beetle attack. The type 2 bark beetle model is switched off after one outbreak has occurred.

Field 1: This specifies the earliest year an outbreak can occur. A year must be specified. There is no default value.

Field 2: This field specifies the tree species elgible for attack by the bark beetle and should be a number between 1 and 11, inclusive, which is the tree species index applicable to your variant of the Prognosis Model. Default is 3, which is Douglas-fir in the Inland Empire variant.

Field 3: This field specifies the minimum d.b.h. (in inches) of trees that will be considered eligible for attack by the bark beetle. The default is 10 inches d.b.h.

Field 4: This field specifies the minimum density of eligible trees as specified by fields 2 and 3, which must be windthrown in the same or prior year within the same time step as this bark beetle event. The default density is 10 eligible trees per acre.

Field 5: This field specifies the mortality rate that will be applied to all eligible trees if an outbreak occurs. The default rate is 0.88 for all eligible trees.

BBTYPE3 This keyword specifies a type 3 bark beetle event, which kills trees infected by root disease. Fir engraver (*Scolytus ventralis*) on grand fir is an example of this type. The user specifies a year and intensity to switch on this agent. Because the pattern of action for type 3

beetles is determined by the density of trees with greater than a specified level of root damage, the model remains active once it is switched on.

Field 1: This specifies the year that is the earliest an outbreak can occur. A year must be specified. There is no default.

Field 2: This field specifies the tree species eligible for attack by the bark beetle and should be a number between 1 and 11, inclusive, which is the tree species index applicable to your variant of the Prognosis Model. The default is 4, which for the Inland Empire variant corresponds to grand fir.

Field 3: This field specifies the minimum d.b.h. (in inches) of trees that will be considered eligible for attack by the bark beetle. The default is 10 inches d.b.h.

Field 4: This field specifies the minimum density of eligible trees as specified by fields 2 and 3 that must be present before an outbreak can occur. The default is 10 trees per acre.

Field 5: This field specifies the mortality rate that will be applied to all eligible tree records if an outbreak occurs. The default mortality rate is 0.88 for all eligible trees.

Field 6: This field specifies the minimum proportion of roots that must be infected for trees to be eligible for attack by this beetle. Trees with a lower infection level are not eligible for attack. The default is 0.30 proportion of the root system infested.

WINDTHR This keyword specifies a windthrow event. The user specifies a year and intensity to switch on this agent. The windthrow model is switched off after an event has occurred. Both uninfected and infected trees are wind-thrown.

Field 1: This specifies the earliest year a windthrow event can occur. A year must be specified. There is no default value.

Field 2: The value in this field specifies the proportion of eligible stems that can be wind-thrown. In a sense, it is a measure of the magnitude of the event. Only dominant and codominant trees of any species (the largest 20 percent in the diameter distribution) are subject to windthrow events. The proportion of these trees to be wind-thrown should be specified. The default is zero, which will result in no trees wind-thrown.

Field 3: This field specifies the minimum density of eligible trees per acre necessary for a windthrow event. The default is zero, and the windthrow event will be independent of the density of eligible stems.

CONSIDERATIONS WHEN USING THE COMBINED MODELS

There are several items that users of this model should consider when deciding how to develop a scenario.

Root Disease Dynamics

Many of the functional relationships that describe how live root systems become infected, how trees are killed, and the progress of infection through roots are based on our current best understanding of root disease pathology. However, default

values for the number of years required to kill trees, lifespan of effective inoculum, and the percentage of a root system that is infected at the time of tree death are representative of conditions in stands in the Inland Empire Region of the Western United States. These values (appendix II) should be adjusted through keywords for other Regions.

Carryover of Root Disease

The carryover model is used to predict the persistence of root disease between rotations in the same stand. There are some restrictions on its use in the current version of the model. First, the carryover model can span only four time steps prior to the time specified for evaluation of carryover. Second, these time steps should be of equal length. Third, the new regeneration affecting the carryover (in addition to the stumps) will be visible to the model only if the regeneration establishment model has been invoked by the user with new trees entering the tree list during the 20 years following the harvest. These options include natural regeneration and planting. Another keyword, TDISTN, should be considered when the planting option is used.

INTERPRETING MODEL OUTPUT

Information in earlier sections of this guide will enable users to prepare scenarios for simulation by the Root Disease and the Prognosis Models. Outputs from the combined models are presented in tables that summarize information on the conditions in the stand during the period covered by the projection. Outputs from the Root Disease Model are:

1. A summary listing of the options specified by keyword and any associated values in effect for the simulation. These include both Root Disease Model and Prognosis Model keywords and are written to the Prognosis Model output file.
2. A table representing the summary statistics for root disease areas. This table displays conditions within the diseased portion of the stand and is written to the Prognosis Model output file.
3. A detailed output file that describes species-specific consequences of root disease infection on tree growth and mortality. These data are written to a separate output file when requested by the keyword RRDOUT.
4. A machine readable file containing all the information in the root disease summary table except table headings. This file is created only when requested by the keyword RRECHO.

The descriptions below focus largely on outputs specific to the Root Disease Model. Prognosis outputs are shown for comparative purposes only; a guide to their interpretation appears in Wykoff and others (1982).

Table of Keywords

Root Disease Model keywords and their parameters that define the scenario are listed with Prognosis Model keywords (table 2). The listing is designed to include only the keywords and their parameters that have been specified in the input data set. If some of the parameters are "out of bounds," warning messages will appear in this table. This listing is intended to help verify that the projection is based on the intended actions as well as to facilitate problem solving. This table is printed on the same file as the Root Disease summary table (table 2). The listing is designed to include only the parameters and options in effect for the simulation; not all possible keywords are listed.

In the example (table 2), keywords for the Root Disease Model begin with RRIN and end with END. These two keywords are left-adjusted in the table. The other Root Disease Model keywords are printed between these and are indented two positions to the right. The parameter values for each keyword are printed after the keyword; some are default values. For example, the parameters for PSTUMP are year (2003), efficiency (0.8), and minimum stump diameter, (3.0). No parameter value was entered for RRDOUT, so the default 22 is printed.

Table 2—Keywords and parameters for the Root Disease Model as reported in the Prognosis Model output file for a stand in Crow Creek on the Lolo National Forest

```
                 STAND GROWTH PROGNOSIS SYSTEM     VERSION 6.0 -- INLAND EMPIRE         01-22-1990  10:41:37

-------------------------------------------------------------------------------------------------------------

                                            OPTIONS SELECTED BY INPUT

-------------------------------------------------------------------------------------------------------------
KEYWORD    PARAMETERS:
--------   --------------------------------------------------------------------------------------------------

STDIDENT
           STAND ID= 16458120         2025 CROW CREEK DATA-R1-ROOT DISEASE

COMMENT
               - RRSETB - TEST ROOT DISEASE MODEL
               - TYPE OF STAND - INVENTORY
               - ROOT DISEASE - ARMILLARIA
               - 7 PLOTS, 2 WITH RD
               - RANDOM CENTERS

END

TREELIST   DATE/CYCLE=    1; DATA SET REFERENCE NUMBER =  3.; HEADING SUPPRESSION CODE = 0.
           (0=WITH HEADING, OTHER VALUES=SUPPRESS HEADING).

DESIGN     BASAL AREA FACTOR=  40.0; INVERSE OF FIXED PLOT AREA=  300.0; BREAK DBH=    5.0
           SEE "OPTIONS SELECTED BY DEFAULT" FOR REMAINING DESIGN CARD PARAMETERS.

STDINFO    FOREST-LOCATION CODE=   116; HABITAT TYPE=530; AGE=  130; ASPECT AZIMUTH IN DEGREES=  45.; SLOPE=  10.%
           ELEVATION(100'S FEET)= 33.0; LATITUDE IN DEGREES=  45.
           HABITAT TYPE MAPPED TO 530 FOR THIS PROJECTION.

INVYEAR    INVENTORY YEAR= 1983

GROWTH     DIAMETER GROWTH DATA TYPE CODE= 0,    5 YEAR MEASUREMENT PERIOD;
           HEIGHT GROWTH DATA TYPE CODE  = 0,    5 YEAR MEASUREMENT PERIOD;
           MORTALITY MEASUREMENT PERIOD  = 5

NUMCYCLE   NUMBER OF CYCLES= 20
```

(con.)

Table 2 (Con.)

```
NOTRIPLE

THINDBH     DATE/CYCLE= 2003; SMALLEST DBH=     1.0; LARGEST DBH=    99.0; PROPORTION OF SELECTED TREES REMOVED= 1.000

TIMEINT     CYCLE=  3; PERIOD LENGTH=  5

TIMEINT     CYCLE=  4; PERIOD LENGTH=  5

TIMEINT     CYCLE=  5; PERIOD LENGTH=  5

TIMEINT     CYCLE=  6; PERIOD LENGTH=  5

TIMEINT     CYCLE=  7; PERIOD LENGTH=  5

TIMEINT     CYCLE= 20; PERIOD LENGTH=  5

ESTAB       REGENERATION ESTABLISHMENT OPTIONS:
            DATE OF DISTURBANCE= 2003

BURNPREP    DATE/CYCLE= 2004; % GROUND=  80.0

PLANT       DATE/CYCLE= 2005; SPECIES= 2.; TREES/ACRE=  500.; % SURVIVAL= 80.00

TALLYONE    DATE/CYCLE= 2007; DATE OF DISTURBANCE=2003.

TALLYTWO    DATE/CYCLE= 2012; DATE OF DISTURBANCE=2003.

RESETAGE    DATE/CYCLE= 2005; NEW AGE=    0.

HTADJ       DATE/CYCLE= 2005; SPECIES NUMBER=  2.; ADJUSTMENT VALUE=    1.5000

END         END OF ESTABLISHMENT KEYWORDS

SPECPREF    DATE/CYCLE= 2008; SPECIES=  2.; THINNING SELECTION PRIORITY=   -2.

THINBTA     DATE/CYCLE= 2013; RESIDUAL= 1000.00; PROPORTION OF SELECTED TREES REMOVED= 1.000
            DBH OF REMOVED TREES WILL RANGE FROM    .0 TO 999.0 INCHES, AND
            HEIGHT OF REMOVED TREES WILL RANGE FROM    .0 TO 999.0 FEET.
```

(con.)

Table 2 (Con.)

```
RRIN       ROOT DISEASE KEYWORDS:

  SAREA      STAND AREA =    51.00 ACRES

  PLREAD     DISEASE SUBPLOTS READ IN
             DISEASED PLOTS=   1   5

  RRTYPE     ROOT DISEASE SIMULATED IS ARMILLARIA

  RRINIT     ROOT DISEASE INITIALIZATION KEYWORD; ROOT DISEASE CENTERS ASSIGNED RANDOMLY
             INITIALIZATION WILL BE WITH USER-SUPPLIED DATA UNLESS THE RRTREIN KEYWORD IS USED IN THE RUNSTREAM
             NUMBER OF CENTERS=   3; INFECTED TREES/ACRE IN DISEASED AREAS =  100.00
             UNINFECTED TREES/ACRE IN DISEASED AREAS =  100.00 ;PROPORTION ROOTS INFECTED= .40 ;DISEASE AREA =  21.00 ACRES

  RRTREIN    ROOT DISEASE INITIALIZATION IS FROM TREELIST

  STREAD     STUMPS READ IN FROM KEYWORD FILE; SUMMARY OF TOTAL NUMBER OF STUMPS IN STAND REPORTED BELOW

  CARRY      DYNAMIC CARRYOVER MODEL, MINIMUM SPREAD=   .00 FT/YR  MODEL CALLED    4 CYCLES AFTER MANAGEMENT

  SPREAD     DYNAMIC SPREAD MODEL

  PSTUMP     DATE/CYCLE= 2003;  EFFICIENCY =  .80;   MIN SIZE =   3.00 INCHES DBH

  RRJUMP     ROOT DISEASE AREA WILL JUMP OUT  1.00 RADII UPON CUT

  RSEED      SEED TO REINITIALIZE RANDOM NUMBER GENEATOR=  11188.00

  RRDOUT     DETAILED ROOT DISEASE OUTPUT ON LOGICAL UNIT   22

END        END OF ROOT DISEASE KEYWORDS

TREEFMT
           (13X,I4,T18,I4,T28,F2.0,T30,I1,T33,A2,F3.1,F2.1,3X,F3.0,T43,F3.0,T54,
           F2.0,T46,I1,T48,3(I2,I1),T22,I1,T22,I1,T63,I2,I3,I3,I1,I1)

TREEDATA   DATA SET REFERENCE NUMBER=  5

PROCESS    PROCESS THE STAND.
```

(con.)

Table 2 (Con.)

```
-----------------------------------------------------------------------------------------

                              OPTIONS SELECTED BY DEFAULT

-----------------------------------------------------------------------------------------

DESIGN     BASAL AREA FACTOR= 40.0; INVERSE OF FIXED PLOT AREA=  300.0; BREAK DBH=    5.0
           NUMBER OF PLOTS=     7; NON-STOCKABLE PLOTS=     0; STAND SAMPLING WEIGHT=   1.00000

-----------------------------------------------------------------------------------------

-----------------------------------------------------------------------------------------

                       SUMMARY OF ROOT DISEASE INFORMATION READ IN ON INPUT

-----------------------------------------------------------------------------------------

           NUMBER OF   INFECTED TREE RECORDS IN DISEASE PATCHES=    6.
           NUMBER OF UNINFECTED TREE RECORDS IN DISEASE PATCHES=   13.

                         NUMBER OF STUMPS

           SIZE CLASS     HEARTWOOD     NON-HEARTWOOD
           ------------------------------------------
             0- 12"        100.              0.
            12- 24"          3.             25.
            24- 48"         11.              0.
            48-100"          0.              0.
              >100"          0.              0.
```

Root Disease Summary Table

The key information in the root disease summary output file is a table of changes within the area infected by root disease. The summary output from the Root Disease Model (table 3) is designed to illustrate a number of important indicators of root disease effects in diseased areas of the stand:

1. Measure of the extent of root disease infection, including the number of infection centers, the mean annual spread rate in feet per year, and the total acres of the stand with root disease.
2. The number of infected stumps and the basal area of those stumps (in square feet per acre).
3. The number of trees per acre killed by root disease in the current growth cycle and the timber volume loss represented by those trees (in cubic feet per acre). Note that the number of trees killed by other agents (if called) are not included here; those losses will be reflected in the stand averages summarized by Prognosis.
4. The number of uninfected trees per acre within disease centers.
5. The number of infected trees per acre in the centers and the average percentage of their root systems that are infected.
6. Economic indicators of the volume (cubic feet per acre), and total basal area (square feet per acre) of live trees in diseased areas.

Column headings in table 3 describe the information in general. Column 1 is the year of the end of the growth cycle. Column 2 is stand age; this age is relevant only if one sets the age in the Prognosis keywords, or resets it in the case of a harvest. Column 3 is the number of root disease centers in the stand. This value is set by a keyword (RRINIT, RRTREIN, or PLREAD). It is reset only if the carryover model is called. Root disease centers merging to form fewer, but larger, centers through time are handled elsewhere in the model on an area-infected basis.

Column 4 is the total area of the stand with root disease. Column 5 is the rate of spread of the disease over the past growth cycle; this is always positive. Reduction of the area in root disease by removal of infected stumps (if PSTUMP is invoked) occurs at the beginning of the growth cycle. Spread rate is calculated from the remaining infected stumps after that removal.

The next four columns are dead tree characteristics, which describe trees killed by root disease. The first of these columns is the number of stumps per acre infected with root disease. Zeros may occur in this column for two reasons. At the start of a simulation the history of the past growth period is undefined. When the infection rate is less than one tree per acre per year in the past cycle, a zero is shown. The next column is the basal area of infected stumps per acre. The last two columns are the number of trees per acre killed and the cubic volume of these trees for the past growth cycle.

Following the summary of dead tree characteristics is a summary of live trees in diseased portions of the stand. First is the number of noninfected trees per acre, then the number of infected trees per acre. After a harvest these values are incorrect. Until the carryover model is finished, newly infected trees are missed by the root disease model when writing this table. Small trees once infected also die within the growth cycle so they may not be seen as infected and alive. The next column is the simulated percentage of the root system infected for all infected trees in the stand. It serves primarily as an index to model performance. This is followed by the merchantable cubic foot volume per acre in the diseased portion of the stand at the end of the cycle. Newly infected trees on the edge of the disease centers are included. The basal area for this same set of trees appears in the next column.

Stand and management identifiers, as specified in the Prognosis keywords, are also listed in this table. All root disease outputs are aggregated across tree species in the root diseased portions of the stand.

As discussed elsewhere in this manual, the most straightforward indicator of the extent of root disease in a stand is the total area within root disease centers. The number of infection centers is presented primarily to verify the initial inventory

Table 3—A summary of conditions within the diseased proportion of the stand as reported in the Root Disease Model output file for a stand in Crow Creek on the Lolo National Forest

ROOT DISEASE MODEL VERSION 1.0

SUMMARY STATISTICS FOR ROOT DISEASE AREAS

		DISEASE STATISTICS			DEAD TREE CHARACTERISTICS: STUMPS		DEAD TREE CHARACTERISTICS: LOSSES FROM DISEASE		LIVE TREE CHARACTERISTICS: UNINF	LIVE TREE CHARACTERISTICS: INFECTED		LIVE TREE CHARACTERISTICS: OVERALL		IDENTIFIERS	
YEAR	AGE	NO OF CENTS	DISEASE AREA ACRES	SPREAD RATE FT/YR	TOTAL /ACRE	BA/ ACRE SQFT	NO OF TREES KILLED	VOLUME LOSSES CU FT /ACRE	NO OF TREES /ACRE	NO OF TREES /ACRE	AVE %ROOTS INFECTED	MERCH CU FT /ACRE	BA/ ACRE SQFT	STAND ID	MGMT ID
1983	130	3	20.93	.00	7.	4.	0.	0.	5258.	78.	40.0	6523.	200.	16458120	NONE
1993	140	3	21.44	.48	9.	14.	269.	163.	3838.	71.	56.1	6349.	203.	16458120	NONE
2003	150	3	21.56	.10	56.	65.	416.	16835.	2709.	17.	37.3	4242.	148.	16458120	NONE
2008	5	3	23.99	.01	13.	22.	323.	33.	2930.	0.	.0	0.	28.	16458120	NONE
2013	10	3	24.01	.04	3.	12.	2.	0.	2908.	0.	.0	0.	35.	16458120	NONE
2018	15	3	24.01	.01	3.	11.	0.	0.	876.	0.	.0	0.	11.	16458120	NONE
2023	20	3	24.01	.03	3.	11.	0.	0.	859.	0.	.0	0.	33.	16458120	NONE
2028	25	86	6.65	.09	3.	11.	4.	1.	840.	2.	65.8	75.	63.	16458120	NONE
2038	35	86	7.44	.11	1.	4.	30.	132.	758.	3.	80.2	728.	119.	16458120	NONE
2048	45	86	7.73	.18	0.	0.	7.	22.	626.	2.	72.5	1984.	164.	16458120	NONE
2058	55	86	10.20	1.01	1.	2.	29.	127.	491.	23.	53.2	3582.	212.	16458120	NONE
2068	65	86	15.16	1.77	11.	23.	50.	914.	356.	43.	50.1	4898.	234.	16458120	NONE
2078	75	86	19.54	1.63	28.	68.	47.	1943.	272.	37.	52.9	4689.	208.	16458120	NONE
2088	85	86	22.29	1.47	46.	88.	35.	1724.	209.	29.	53.8	4278.	180.	16458120	NONE
2098	95	86	25.28	1.98	27.	45.	16.	214.	169.	32.	58.9	5462.	200.	16458120	NONE
2108	105	86	27.57	1.77	20.	35.	19.	1271.	140.	27.	58.7	5530.	190.	16458120	NONE
2118	115	86	30.37	2.50	25.	55.	16.	1262.	117.	24.	54.8	5531.	180.	16458120	NONE
2128	125	86	31.94	1.61	21.	50.	11.	1030.	98.	21.	57.3	5493.	170.	16458120	NONE
2138	135	86	34.44	2.43	17.	46.	10.	1192.	87.	18.	54.5	5582.	165.	16458120	NONE
2148	145	86	36.47	2.31	15.	41.	8.	880.	76.	16.	54.5	5918.	165.	16458120	NONE
2153	150	86	37.74	3.46	15.	53.	5.	930.	70.	17.	46.0	5613.	156.	16458120	NONE

and to illustrate the outcome of carryover after a cut. No attempt is made by this version of the model to merge overlapping centers, although overlaps are taken into account when calculating the area infected with disease. In addition, the number of centers is prevented from increasing beyond 100 for the stand.

Interpretation of entries in the output tables for periods between a stand harvest and execution of the carryover model requires some special considerations. After the carryover model produces an estimate of the number of new disease centers (displayed in the output tables), the number of new centers remains constant until either the carryover model is called again or the area in root disease goes to zero. That is, although those centers may be spreading and coalescing, the model output does not display the "effective" number of disease centers. Thus, the number of root disease centers has meaning only for the cycle following completion of the carryover model; a more general indicator of root disease infection in stands is simply the total area in root disease. At present, the output tables (tables 3 and 4) do not accurately reflect disease conditions of the regeneration until after carryover has been executed. To check that CARRY has been executed, refer to the Activity Summary listed by Prognosis Event Monitor (Crookston 1985) just after the Summary Yield Tables.

Some comparisons will likely be made between the Root Disease Model summary, table 3, and the summary from the Prognosis Model, table 5. The critical issue to remember is that the Prognosis summary is for the entire stand including both the portion infested with root disease, and the portion uninfested. Infested area changes from one projection cycle to the next.

The Prognosis Model summary contains several columns of data that correspond directly to entries in the Root Disease Model summary table. In table 5 these are the columns labeled YEAR, AGE, TREES/ACRE, BA/ACRE, MERCH CU FT, ACC, and MOR. The first two columns should be identical to the first two columns in table 3. The third column refers to the number of live trees per acre; in table 3 this number is broken down into live noninfected and live infected trees per acre. The merchantable cubic foot volume per acre is the same measurement in both tables, except for the area to which the value applies. Both accretion (ACC) and mortality (MORT) appear in the Prognosis Model summary, but only mortality from root disease appears in the output table for the Root Disease Model. If the mortality level for the Prognosis Model is greater than that for the Root Disease Model, the Prognosis Model level is used in both tables.

Conditions in uninfested proportions of the stand can be obtained from these two tables by taking the values from table 5 and converting them to totals for the entire stand area and converting values from table 3 to a total for the area infested at that growth cycle. The stand total minus the disease area total is then divided by the area of the stand that is uninfested to get a per acre value for that part of the stand.

A second copy of the summary table can optionally be written to a supplementary output unit as specified with the RRECHO keyword. This copy of simulation results can be used as input to other analyses.

Detailed Output Table

Use of the RRDOUT keyword causes a more detailed output table to be printed (table 4). This table displays some measures of the effects of root disease on attributes of each tree species in diseased areas. At the time of stand inventory, and at the end of each cycle, the number of trees killed during that cycle and the number of alive uninfected and alive infected trees are displayed. In addition, five percentile classes for tree d.b.h. are presented, along with the size of the largest tree in each class for both the trees killed by root disease and live trees. This detail is intended to illustrate species-specific growth effects in the root-diseased areas of the stand.

The detailed output table is written to a separate file from all other model output. This output is controlled by the keyword RRDOUT. The additional information that is not in the root disease summary output table is the breakdown by size classes within species of the frequency and condition of trees within the root disease centers.

Table 4—A detailed summary of tree conditions within the diseased proportion of the stand by tree size class by species as reported in the Root Disease Model output file (RRDOUT) for a stand in Crow Creek on the Lolo National Forest

ROOT DISEASE MODEL EXTENSION VERSION 1.0

STAND ID= 16458120 MANAGEMENT ID= NONE

STAND ATTRIBUTES INSIDE ROOT DISEASE PATCHES

YEAR	AREA IN ROOT DISEASE	SP	KILLED TREES %TILE POINTS BY DBH (INCHES) 10	30	50	70	90	100	TOTAL TREE TREES/ACRE	ALIVE TREES %TILE POINTS BY DBH (INCHES) 10	30	50	70	90	100	TOTAL UNINFECTED TREES/ACRE	TOTAL INFECTED TREES/ACRE	% ROOTS INFECTED
1983	20.9																	
		WP	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.00
		L	.0	.0	.0	.0	.0	.0	.0	39.6	39.6	39.6	39.6	39.6	39.6	2.3	2.6	.00
		DF	.0	.0	.0	.0	.0	.0	.0	.1	.1	.1	.1	.1	.1	2700.0	8.0	.00
		GF	.0	.0	.0	.0	.0	.0	.0	.1	1.7	3.3	3.3	3.3	3.3	1350.0	59.4	.00
		C	.0	.0	.0	.0	.0	.0	.0	.5	25.6	25.6	25.6	25.6	25.6	1055.6	.0	.00
		LP	.0	.0	.0	.0	.0	.0	.0	.5	25.6	25.6	25.6	25.6	25.6	.0	.0	.00
		S	.0	.0	.0	.0	.0	.0	.0	4.9	4.9	4.9	4.9	4.9	4.9	150.0	.0	.00
		PP	.0	.0	.0	.0	.0	.0	.0	4.9	4.9	4.9	4.9	4.9	4.9	.0	7.8	.00
2003	21.6																	
		WP	5.3	5.3	5.3	5.3	5.3	5.3	.0	34.8	34.8	34.8	34.8	34.8	34.8	.0	.0	7.92
		L	37.0	37.0	37.0	37.0	37.0	37.0	18.6	41.8	41.8	41.8	41.8	41.8	41.8	3.4	2.5	25.78
		DF	28.3	28.3	28.3	28.3	28.3	28.3	197.5	28.3	28.3	28.3	28.3	28.3	28.3	1208.4	6.7	65.18
		GF	1.8	1.8	24.6	24.6	24.6	24.6	142.4	1.8	24.6	24.6	24.6	24.6	24.6	609.9	.2	60.87
		C	35.9	35.9	35.9	35.9	35.9	35.9	40.0	50.2	50.2	50.2	50.2	50.2	50.2	803.5	1.0	31.62
		LP	4.6	4.6	5.9	7.0	7.0	9.2	.9	4.6	4.6	5.9	5.9	5.9	9.2	2.9	.4	20.56
		S	5.7	5.7	5.7	5.7	5.7	5.7	16.3	5.7	5.7	5.7	5.7	5.7	5.7	81.1	.0	.00
		PP	5.7	5.7	5.7	5.7	5.7	5.7	.0	5.7	5.7	5.7	5.7	5.7	5.7	.0	6.4	13.48

(con.)

Table 4 (Con.)

2008	24.0																	
		L	5.7	5.7	5.7	5.7	5.7	5.7	.0	.4	.4	.4	.4	.4	.4	537.8	.0	.00
		DF	1.5	1.5	1.5	1.9	1.9	1.9	70.6	1.5	1.5	1.5	1.5	1.5	1.9	1084.7	.0	.00
		GF	2.0	2.0	2.0	2.0	2.0	2.2	244.3	.9	.9	2.0	2.2	2.2	2.2	534.0	.0	.00
		C	1.7	1.7	1.7	1.7	1.7	1.7	8.2	1.7	1.7	1.7	1.7	1.7	1.7	692.1	.0	.00
		LP	1.7	1.7	1.7	1.7	1.7	1.7	.0	.5	.5	.5	.5	.5	.5	74.7	.0	.00
		S	1.7	1.7	1.7	1.7	1.7	1.7	.0	.4	.4	.4	.4	.4	.4	5.1	.0	.00
		PP	1.7	1.7	1.7	1.7	1.7	1.7	.0	.6	.6	.6	.6	.6	.6	1.7	.0	.00
2028	6.7																	
		L	1.9	2.3	2.3	2.3	2.8	2.8	.0	2.3	2.9	3.4	6.3	7.6	7.8	467.1	.9	60.21
		DF	2.1	2.6	5.0	5.0	5.0	5.0	1.0	2.1	2.6	2.6	5.0	5.0	5.0	81.1	.0	.00
		GF	1.3	2.9	3.9	5.5	5.5	5.5	2.0	1.3	1.3	2.1	7.5	7.5	7.5	116.3	1.0	71.44
		C	.9	1.0	1.3	1.3	3.4	3.4	.1	.9	.9	1.3	1.3	3.4	3.4	88.4	.0	.00
		LP	1.5	2.9	2.9	2.9	2.9	2.9	.5	1.5	2.0	2.9	3.2	3.2	3.2	72.9	.0	27.91
		S	.4	.9	1.0	1.1	1.1	1.1	.1	.4	.4	.9	1.0	1.1	1.1	12.1	.0	.00
		PP	.4	.9	1.0	1.1	1.1	1.1	.0	3.4	3.4	3.4	3.4	3.4	3.4	1.7	.0	24.60
2153	37.7																	
		L	15.2	15.7	21.7	25.5	25.5	25.5	1.2	11.6	13.8	19.9	19.9	23.0	28.3	51.9	10.5	50.41
		DF	9.1	11.8	13.0	13.0	13.0	13.0	.1	8.2	11.8	15.7	18.5	18.5	18.5	.5	.4	47.71
		GF	31.3	31.3	31.3	31.3	31.3	31.3	3.3	22.6	31.3	31.3	31.3	31.3	31.3	1.1	4.6	35.15
		C	3.2	3.2	8.7	18.1	18.1	18.1	.1	3.7	4.5	4.5	4.8	4.8	18.1	15.8	.9	50.53
		LP	6.0	10.6	11.7	11.7	11.7	11.7	.0	6.0	8.5	9.5	11.7	11.7	11.7	.3	.1	15.59
		S	2.5	2.6	3.5	3.5	3.5	3.5	.0	3.5	4.0	4.0	4.0	4.2	4.2	.2	.0	70.89
		PP	2.5	2.6	3.5	3.5	3.5	3.5	.0	7.8	7.8	7.8	7.8	7.8	7.8	.0	.0	10.04

Table 5—A summary for the entire stand as reported in the Prognosis Model output file for a stand in Crow Creek on the Lolo National Forest

STAND GROWTH PROGNOSIS SYSTEM VERSION 6.0 -- INLAND EMPIRE 01-22-1990 10:43:08

SUMMARY STATISTICS (PER ACRE OR STAND BASED ON TOTAL STAND AREA)

		START OF SIMULATION PERIOD									REMOVALS				AFTER TREATMENT					GROWTH THIS PERIOD			
YEAR	AGE	NO OF TREES	BA	SDI	CCF	TOP HT	QMD	TOTAL CU FT	MERCH CU FT	MERCH BD FT	NO OF TREES	TOTAL CU FT	MERCH CU FT	MERCH BD FT	BA	SDI	CCF	TOP HT	RES QMD	PERIOD YEARS	ACCRE PER	MORT YEAR	MAI MERCH CU FT
1983	130	8349	242	791	255	113	2.3	9151	8022	37853	0	0	0	0	242	791	255	113	2.3	10	209	89	61.7
1993	140	6118	293	868	333	117	3.0	10354	9220	43160	0	0	0	0	293	868	333	117	3.0	10	144	68	65.9
2003	0	4528	282	793	310	123	3.4	10195	9151	42883	742	10157	9151	42883	11	54	31	7	.7	5	56	1	.0
2008	5	4241	57	217	130	12	1.6	313	0	0	0	0	0	0	57	217	130	12	1.6	5	55	0	.0
2013	10	4196	80	284	175	17	1.9	587	0	0	3196	563	0	0	5	21	9	17	.9	5	20	0	.0
2018	15	946	18	64	29	23	1.9	125	0	0	0	0	0	0	18	64	29	23	1.9	5	58	0	.0
2023	20	930	47	138	66	27	3.1	416	0	0	0	0	0	0	47	138	66	27	3.1	5	101	1	.0
2028	25	912	84	219	108	34	4.1	920	325	1011	0	0	0	0	84	219	108	34	4.1	10	161	4	.0
2038	35	845	173	385	190	43	6.1	2495	1640	6410	0	0	0	0	173	385	190	43	6.1	10	265	21	.0
2048	45	706	265	522	268	56	8.3	4936	4251	20134	0	0	0	0	265	522	268	56	8.3	10	205	46	.0
2058	55	579	300	556	294	65	9.7	6523	5896	29365	0	0	0	0	300	556	294	65	9.7	10	183	83	.0
2068	65	457	308	541	294	72	11.1	7524	7014	35250	0	0	0	0	308	541	294	72	11.1	10	143	121	.0
2078	75	363	293	496	274	78	12.2	7745	7330	36959	0	0	0	0	293	496	274	78	12.2	10	133	127	.0
2088	85	290	274	450	252	84	13.2	7802	7441	37592	0	0	0	0	274	450	252	84	13.2	10	157	74	.0
2098	95	242	279	441	252	89	14.5	8632	8297	42680	0	0	0	0	279	441	252	89	14.5	10	144	113	.0
2108	105	204	271	417	241	94	15.6	8943	8636	44804	0	0	0	0	271	417	241	94	15.6	10	112	121	.0
2118	115	172	256	385	224	99	16.5	8847	8572	44756	0	0	0	0	256	385	224	99	16.5	10	116	113	.0
2128	125	147	245	360	212	102	17.5	8873	8616	45474	0	0	0	0	245	360	212	102	17.5	10	117	119	.0
2138	135	128	234	338	200	106	18.3	8854	8612	45773	0	0	0	0	234	338	200	106	18.3	10	132	104	.0
2148	145	112	230	324	194	111	19.4	9138	8901	47501	0	0	0	0	230	324	194	111	19.4	5	105	177	.0
2153	150	104	219	307	183	112	19.6	8781	8553	45722	0	0	0	0	219	307	183	112	19.6	0	0	0	.0

For the most part, column and row headings are sufficient to interpret the contents of this table. Realize that the table summarizes by time steps the conditions at the end of a growth cycle and the changes that took place within the past cycle.

The first section of the table is for the base year (usually inventory). For this point in time, a breakdown of tree density is presented for live trees but not for mortality. Instead, a section of zeros is printed because the model does not summarize periodic mortality in the time before the date of inventory.

The size class breakdown within a species is by five percentile classes. Diameter distributions between species may vary greatly and are sometimes based on a small number of sample trees. A detailed diameter distribution is available as a Prognosis option. However, this distribution is for the entire stand, not just the area in root disease. Thus, the Prognosis summary will differ from the breakdown within the root-diseased portion of the stand. Following harvest and reestablishment, and prior to the time at which the Carryover Model is invoked, values for trees killed per acre represent newly established trees being infected and killed by the normal Root Disease Model within the infection centers as they existed at the time of the cut. During this interval (such as in table 4, in year 2008) there are no entries for total infected trees, or percentage of roots infected. After the Carryover Model is run, the model will have a set of new infection centers and an estimate of number of trees infected and percentage of roots infected. From that point on, this table represents the new area infected.

HOW THE MODEL WORKS

The Root Disease Model simulates the epidemiology of pathogenic *Armillaria* spp. or *P. weirii*. The model simulates spatial relationships between location of infected stumps and infected and uninfected live trees to predict the spread of infection in the stand. Persistence of infection between rotations is also simulated. The major relationships captured in the model are the susceptibility of trees to infection, vulnerability of trees to death once infected with root disease, effects of windthrow and attack by bark beetles, disease related growth reduction, and inoculum dynamics in infected trees and stumps. Physical and biological agents that may influence the dynamics of root disease incidence can optionally be included in the simulation.

The parameters used as defaults in the model reflect our best current understanding of *Armillaria* and *P. weirii* epidemiology in the Inland Empire region of the western United States. These parameters can be adjusted using keywords to more accurately reflect particular pathogenicities and stand conditions (appendix II).

The dynamics and impact of root disease in a stand projection is modeled in roughly six major parts:

1. Representation of root disease centers at the start of a simulation.
2. Simulation of the effects of other mortality agents on trees inside root disease centers.
3. Simulation of the spread of root disease centers.
4. Dynamics of the infection of trees inside root disease centers.
5. Estimation of the "carryover" of root disease from one stand through a harvest to a new stand with new infection centers.
6. Calculation of mortality inside root disease centers and growth effects due to root disease.

Brief descriptions of each of these phases will serve as background for describing input requirements, interpretation of output, and understanding model behavior. For additional detail, refer to McNamee and others (1989).

Representation of Root Disease Centers at Start of Simulation

The Prognosis Model represents the stand by a list of sample tree records. Each record in the list represents a number of trees in the stand with identical attributes. The number of trees per unit area represented by each record at the time of inventory is determined by the sample design. In addition to the number of trees, each record includes the species of the tree and its d.b.h., height, and crown ratio.

After Prognosis compiles the stand inventory and prescriptions for selected management actions, the root disease inventory is used to characterize diseased portions of the stand. Inventory data can be generated in two ways: (1) exclusively through keywords specified by the user, or (2) a combination of keywords specified by the user and data obtained directly from the input tree list used by Prognosis. Regardless of the method used, the following information is needed:

1. The number and size of root disease centers and their locations (unless a random distributionof locations is assumed).
2. The number of infected and uninfected trees within root disease centers (input through keyword or supplied directly from tree list) and the average proportion of root systems infected on infected trees (always keyword supplied).
3. A list of infected stumps (including infected dead trees) inside the root disease centers, and their sizes. This stump information can be entered through keywords, read directly from the tree list, or both for a given scenario.

In the model, the stand is assumed to be square and infection centers within it are assumed to be circular. The total density of infected and uninfected trees of each tree record inside the disease centers is computed from the input tree list or from the keyword, RRINIT, supplied by the user.

The proportion of root systems colonized on infected trees at the time of inventory can be defined by the user. Once simulation begins, this proportion is calculated separately for each tree, and thus the average for all infected trees will change.

Dead tree and stump information is summarized from the input tree list, from a user specified keyword, or both. Dead trees and stumps, in the context of the Root Disease Model, are defined as any tree that died infected with root disease, whatever the cause of death. The model assumes that trees uninfected with root disease at the time of death do not become inoculum sources. The remaining dead trees or stumps can be a whole standing tree, a standing bole, or a bole that has been snapped off. These dead trees and stumps act as inoculum sources for root disease in the infection centers.

Following the initialization of stand conditions and extent of root disease within the stand, the summary of the initial inventory is completed and the stand projection begins.

Effects of Other Agents

Effects of windthrow and bark beetles on tree mortality may be simulated if desired. These agents interact with the root disease process primarily by influencing inoculum levels and potential disease spread. For example, trees killed by bark beetles can become *Armillaria* inoculum only if they were infected by the fungus prior to death. The killing by beetles of uninfected trees near disease centers could slow disease spread because the model assumes that these root systems will not become inoculum. The other agents submodel is actually a collection of separate models, each of which simulates the action of one type of agent on trees in the stand. These models require the user to specify timing and severity of the event.

Through keywords the user can specify the occurrence of one or more of these agents during any desired cycle year of the projection. The user specifies the earliest year in which the other agent of interest can occur. If the required conditions are not appropriate in that cycle, the agent remains potentially active until conditions are appropriate, and then the event occurs. Only one incident of BBTYPE 1 and BBTYPE2 is permitted.

Windthrow of Trees—The windthrow model simulates major blowdown events in infection centers. Dominant and codominant trees are wind-thrown if the density of eligible stems exceeds a user-defined minimum. For infected trees that are wind-thrown, the model determines the number of stems that tip over, removing their root systems from the soil, as opposed to snapping off and thus leaving the root system in the ground. This decision is based on the proportion of the root systems that are infected. Windfallen stems that tip over do not further contribute to the spread of root disease. Infected trees that are snapped off are entered in the dead tree/stump list and become inoculum sources for root disease.

Bark Beetle Interactions—The current version of the other agents submodel simulates three types of bark beetle-stand interactions:

Type 1 beetles—An outbreak of type 1 beetles occurs when the density of susceptible trees of a given species and minimum diameter exceeds a user-defined minimum. Mountain pine beetle attacking lodgepole pine stands is used as the prototype interaction from which parameters for type 1 interactions are set. Mountain pine beetle and western pine beetle attacking ponderosa pine are also type 1 interactions.

Type 2 beetles—These depend on trees wind-thrown in the current time step. An outbreak occurs if the number of windfallen stems of a suitable size exceeds a user-specified minimum. Standing live trees are also attacked in proportion to their density and the density of wind-thrown trees that are attacked. The user must also specify a windthrow event with a type 2 bark beetle interaction. Douglas-fir beetle attacking Douglas-fir is used as the prototype type 2 beetle interaction from which defaults are set.

Type 3 beetles—An outbreak of type 3 beetles occurs if the density of a given tree species with sufficient size and proportion of their root systems infected exceeds a user-defined minimum density. That is, this type of beetle interaction is dependent on root disease infection, and tree species, size and density. Each of these can be specified by the user. Fir engraver attacking grand fir is used as the prototype type 3 interaction from which parameters are estimated.

In all of these bark beetle-stand interactions, the infected trees that are killed by an outbreak are added to the dead tree/stump list to act as inoculum.

Spread of Infection Centers

The spread of infection centers can be simulated dynamically or it can be set to a predefined rate by the user. If the latter option is chosen, the user specifies the annual rate (feet per year) at which to expand infection centers. If the dynamic spread model is chosen (the default), then the spread rate is simulated in the following way:

Figure 2 shows the basic relationship of how live root systems become infected, trees are killed, and infection spreads in dead roots. The average portion of a root system that is colonized when a tree dies is a function of the pathogen and tree species. The number of years it takes for a given root disease pathogen to kill a tree is a function of tree species and size.

The time necessary to kill a Douglas-fir tree on Douglas-fir habitat in the interior region of the Western United States is defined by the relationship shown in figure 3. This relationship is modified for other species, pathogens, and habitat types, as shown in the figure, but assumes that all trees react to infection in a similar way until their d.b.h., and hence their time-to-death exceeds some minimum.

Following tree death, fungal spread through the root system depends on the species of pathogen. *Armillaria* is assumed to colonize the entire root system within 5 years. *Phellinus weirii* is assumed to be unable to colonize the rest of the root system after death. But *P. weirii* inoculum on dead trees and stumps is assumed to have a minimum lifespan of 20 years. There is no minimum lifespan for *Armillaria* on dead trees and stumps. The maximum lifespan of inoculum is a function of stump size and tree species (fig. 4). Tree species are grouped into

heartwood and nonheartwood types. Species with heartwood include Douglas-fir, pines, western redcedar, and western larch. Nonheartwood species are true firs, hemlocks, and spruce. Inoculum is assumed to decay at a rate that reduces the radial extent of infected root systems by 75 percent during the first one-third of the lifespan. Remaining infected roots are assumed to decay at a steady rate over the remaining two-thirds of their lifespan.

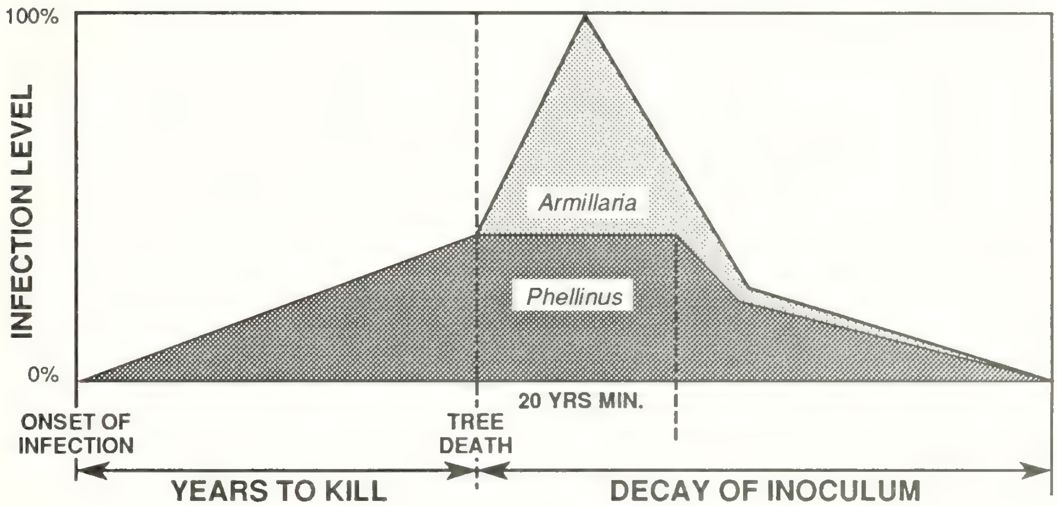

Figure 2—Patterns of pathogen spread and inoculum development in a single root system. Time scales depend on tree species.

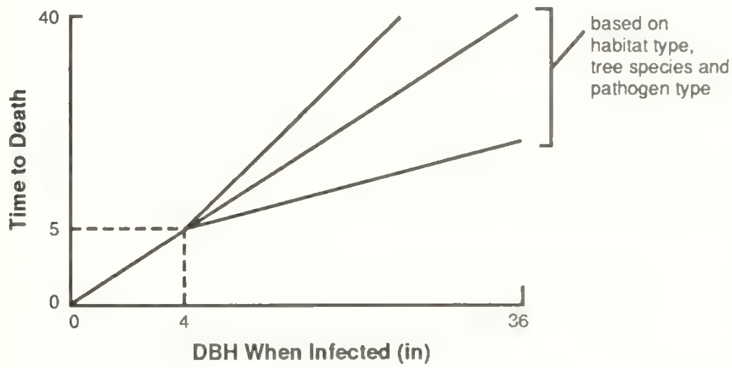

Figure 3—Time required from infection by *Armillaria* to tree death for Douglas-fir on a Douglas-fir habitat type.

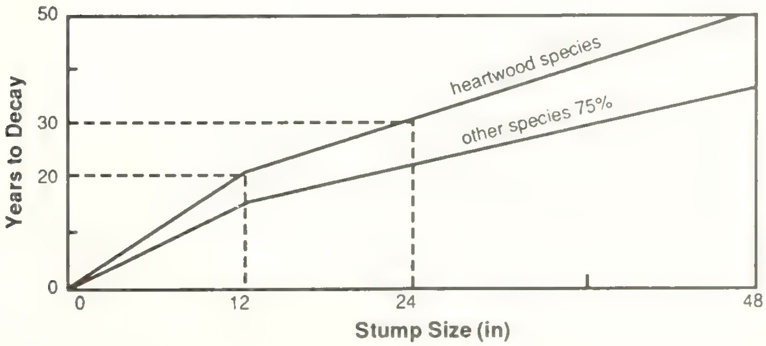

Figure 4—Lifespan of inoculum for various tree species infected with *Armillaria*; see text for description.

Spread rate is calculated by explicitly simulating a small portion of the stand for a number of years and averaging the spread rate of root disease over that period. Trees are selected from the tree list in proportion to their density in the stand and placed in a small "test plot" in either a random pattern (the default) or a square grid pattern with a small, positive amount of "error" in tree placement. These spatial patterns can be used to simulate the spread of root disease in stands under conditions ranging from natural regeneration in the stand to a plantation with little or no natural regeneration. Spread is simulated by increasing the area of infection of each infected root system using the relationship shown in figure 2, then checking to see whether this root system contacts any uninfected root systems. If they do, the uninfected trees contacting the infected trees become infected at a rate equal to the probability of pathogen transmission on contact (dependent on tree species and root disease pathogen). For simplicity, degree of root overlap is ignored in the estimation of probability—the probability is the same whether one or more systems come into contact.

Spread rate is converted to an increase in the radius of each disease center for the current growth cycle. These increased radii are then converted into an increase in total root disease area in the stand for that cycle, taking into account the overlaps between centers. The average spread rate is converted to an annual rate expressed in feet per year for the summary output display.

Old infection centers are assumed to expand at the time of the cut if the root disease pathogen is *Armillaria*. This is because many of the root systems at the edge of the infection center have just become infected with root disease, and *Armillaria* is assumed to completely colonize these root systems after tree death. The user can specify, through a keyword option (RRJUMP), by how many root-system diameters the center will expand after a cut.

Infection Dynamics Inside Centers

Not all trees inside infection centers develop root disease. This part of the model simulates pathogen transmission from infected to uninfected trees within the infection centers.

A representative sample of inoculum (infected stumps) is placed on the plot in a similar way to the live trees for the spread model above. Then trees from the tree list are distributed randomly on this test plot in proportion to their density. The number of newly infected trees inside infection centers is estimated, depending on the proportion of the root systems of each tree that contacts inoculum sources and the probability of infection from that contact.

Carryover of Root Disease to a New Stand

This model component represents our best, albeit incomplete, understanding of the ways in which root disease centers are affected by the harvest of trees and subsequent regeneration of a new stand. For example, the integrity of root disease centers from the old stand may break down after a clearcut. The disease in the new stand may arise from only a few isolated inoculum sources within the previously infected area. Or the centers may remain essentially whole after the clearcut. Or centers in the new stand may rapidly coalesce and expand from essentially the old boundaries. These possibilities are part of a continuum that is determined by the density of inoculum, the composition of the original stand, and the composition of the regenerating stand.

The user has two options for specifying how carryover of root disease is to be modeled. The user can simply set the expected probability of new center initiation and the expected number of new infection centers created after carryover. This option, termed the "static" carryover model, is the default. The second option uses the same relationships for disease spread and pathogenicity used by the main Root Disease Model to estimate carryover of disease from one stand to the next. This option is called the "dynamic" carryover model. Its operation is discussed more fully below.

The carryover model calculates the probability of infection persisting from the time of the cut through to the time of root closure in the new stand. This is done by

reconstructing conditions at the time of the cut and keeping track of the probabilities of infection persisting from the original stumps and from young trees that become infected through contact with old infected stumps or other infected trees. The time step used by the carryover model for this reconstruction is 5 years. This submodel uses the same relationships as those used in the estimation of root disease spread and infection. After the simulation of carryover is completed, the probability of infection persisting is converted into an estimate of the number of new infection centers. The model allows up to 100 new centers to be created from carryover; these new centers are randomly distributed within the boundaries of the old infection centers.

Mortality and Growth Effects Inside Centers

The final part of the Root Disease Model is to reconcile the mortality from root disease and other agents, and growth effects due to root disease in infected trees, with stand averages calculated by Prognosis. These rates are then passed back to Prognosis.

Trees outside root disease centers and uninfected trees inside root disease centers can suffer mortality from causes represented by Prognosis and other agents, while infected trees inside the root disease centers can suffer mortality from causes represented by Prognosis, other agents, and root disease. The model assumes that the total mortality on any tree class will be the maximum of the mortality predicted by Prognosis or the mortality predicted by the combined effect of root disease or other agents.

Root disease infection can affect both diameter and height increment and is modeled as a function of the proportion of the root system colonized by root disease. These relationships are applied only to infected trees; the actual growth increments for each Prognosis tree record are a weighted average of the separate growth increments of the three categories of trees represented by each record: infected inside centers, uninfected inside centers, and trees outside centers. Finally, the Root Disease Model updates the attributes in the dead tree/stump list, and passes control back to Prognosis. The projection continues as Prognosis updates the attributes of the trees in the stand, calculates tree volumes, compiles the tables that display projected stand conditions, and if required, begins the next cycle. At the conclusion of the projection, the Prognosis stand tables are displayed as are the tables summarizing conditions within root disease centers.

Linkage to Prognosis Model and Limitations

Coastal forest conditions were included in development of the Root Disease Model. At this time, however, a Prognosis Model variant has not been developed for coastal forests. This Root Disease Model could be linked to other stand growth models in addition to Prognosis Model. The essential requirements are:

1. A list of trees in the stand, with each tree representing a number of trees per acre on a sampling basis.
2. A regeneration component to add new trees as growing space is released by mortality or harvest.
3. A procedure for compressing the tree list to make space for the new trees.

The limited length of the tree list (500 tree records) imposes some limitation on the representation of the root disease process. The most serious limitation is the necessity of having each tree record represent trees both infected and uninfected, and both inside and outside root disease centers. The consequence of this limitation is that tree attributes such as crown ratio, height increment, and diameter increment must be maintained using weighted averages of the values for trees in each condition. However, this limitation does not apply at the start of the simulation if the disease status of each tree in the inventory is supplied using the RRTREIN option. A further consequence of having each tree record represent trees in all disease conditions is that their growth rates (before modification for effects of infection) are based on overall stand stocking.

An alternative model formulation that would remove this limitation would be to maintain each annulus of spread as an independent stand. Such a formulation would be possible with the Parallel Processing Extension of the Prognosis Model (Crookston and Stage in press). At this time, however, we do not believe that the improved resolution would be justified in view of the other approximations of the disease process implicit in the rest of this model.

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APPENDIX II—REAL WORLD VS. THE MODEL: CHANGING MODEL ASSUMPTIONS

These keywords offer the user flexibility in exploring the dynamics of the model by altering important keywords (the INFKILL, INFMULT, INOCSPAN, RRJUMP, RRMINK, TDISTN, and TTDMULT keywords) and modifying the simulation of important processes such as the spread of disease centers, and carryover between rotations (the SPREAD and CARRY keywords). The RSEED keyword allows the user to vary the random numbers used by the model in calculating spread rate and the dynamics of infection inside root disease centers.

CARRY — Specifies the type of carryover model to be simulated (static or dynamic). The default is that a static carryover model is simulated.

- Field 1: Contains either a 0 or 1. If 0 is entered or field is left blank, a static carryover model is assumed and an entry in field 3 will be read, specifying the fixed probability of forming new disease centers. If 1 is entered, the dynamic carryover model is assumed and field 3 will be searched for the minimum spread rate at root closure.
- Field 2: This contains the number of Prognosis growth cycles after harvesting (thinning or clearcutting) that the carryover model will be called. The default is four cycles. Additional harvesting within the delay interval will, in turn, delay the execution of CARRY.
- Field 3: The entry in field 3 depends on whether the user invokes a static or dynamic carryover model. If field 1 is 0 or blank, a static carryover model is being invoked and field 3 contains the probability of forming new disease centers. The default is a probability of 1.0. An error message will appear if the entry in field 3 is less than 0 or greater than 1, and the default probability will be retained. If field 1 contains 1, the dynamic carryover model will be simulated and field 3 should contain the minimum rate of disease spread at root closure.
- Field 4: Field 4 is only examined if the user has specified a static carryover model. Field 4 contains the number of new disease centers in the entire stand that will be formed when the carryover model is invoked. From one to 100 centers can be established in this way. The default value of three centers will be used if the user specifies less than one or greater than 100 centers.
- DEFAULT: Static spread model called four growth cycles after every stand thinning, including clearcutting.

INFKILL — Infection through a root system proceeds until a threshold proportion of the root system is infected and the tree dies. This keyword allows the user to modify the proportion of the root system that is infected at the time of death.

- Field 1: This field defines for which type of root disease the proportions are to be specified. A value of 1 specifies *Armillaria*, 2 specifies *P. weirii*. Any other value entered on this line will cause an error message to be printed and the *Armillaria* type to be assumed.

However, if the disease specified in this field differs from that specified by the RRTYPE keyword, this keyword will be ignored.

Field 2: The value entered in this field, if between 1 and 11 inclusive, specifies that a single proportion of roots infected at death value is to be changed and indicates the tree species index to be changed. Any other value indicates that all proportions of root infection at death are to be changed, and a supplemental record is to be provided with the new values.

Field 3: This field is only examined if field 2 has a value between 1 and 11 inclusive. It contains the new proportion of root systems infected at death for the species indexed in field 2.

Supplemental Records

A supplemental record is expected if the proportion of roots infected at death is to be changed for all species (Field 2 is not a number between 1 and 11 inclusive). Format for this supplemental record is 11F5.2.

DEFAULT:

Species abbrev.	WP	L	DF	GF	WH	C	LP	S	AF	PP	OTH
Species index	1	2	3	4	5	6	7	8	9	10	11
Armillaria	0.3	0.85	0.8	0.8	0.8	0.75	0.3	0.75	0.3	0.3	0.3
P. weirii	0.85	0.75	0.8	0.6	0.8	0.75	0.85	0.65	0.60	0.85	0.8

INFMULT This keyword allows the user to change the probabilities of disease transmission given that the vertical projections of the infected and uninfected root systems overlap. As one example of the use of this keyword, the user may change infection probabilities for each tree species to represent differences in various habitats.

Field 1: This field contains the year in which the probabilities of infection modified with this keyword are to take effect. This allows the user to change these parameters once during the simulation. The user must put the year in field 1 on all INFMULT keywords that refer to probabilities of infection changed at some point during the simulation. The year in which the probabilities of infection are changed is the date specified on the last INFMULT keyword that has a year in field 1.

Field 2: This field defines for which type of root disease the probabilities are to be specified. A value of 1 specifies *Armillaria*, 2 specifies *P. weirii*. Any other value entered on this line will cause an error message to be printed and *Armillaria* to be assumed. However, if the disease specified in this field differs from that specified by the RRTYPE keyword, this keyword will be ignored.

Field 3: The value entered in this field, if between 1 and 11 inclusive, specifies that a single probability of infection is to be changed and indicates the tree species index to be changed. Any other value indicates that all probabilities are to be changed and a supplemental record is to be provided with the new probabilities.

Field 4: This field is only examined if field 3 has a value between 1 and 11 inclusive. It contains the new probability of infection for the species indexed in field 3.

Supplemental Records

A supplemental record is expected if all probabilities are to be changed (field 3 is not a number between 1 and 11 inclusive). Format for this supplemental record is 11F5.2.

DEFAULT:

Species abbrev.	WP	L	DF	GF	WH	C	LP	S	AF	PP	OTH
Species index	1	2	3	4	5	6	7	8	9	10	11
Armillaria	0.1	0.05	0.5	0.6	0.1	0.1	0.2	0.5	0.5	0.2	0.1
P. weirii	0.1	0.2	0.4	0.4	0.2	0.02	0.1	0.2	0.4	0.1	0.4

INOCSPAN This keyword specifies the minimum lifespan, in years, of inoculum for the two root disease types.

Field 1: This field contains the minimum lifespan of the *Armillaria* root disease type.

Field 2: This field contains the minimum lifespan of the *P. weirii* root disease type.

DEFAULT: 0 years for the *Armillaria* type and 20 years for the *P. weirii* type.

RRCOMP Prognosis tree list arrays are 1,350 records long. In an effort to conserve computer memory requirements but maintain good representation of trees inside disease centers, the root disease tree lists are 500 records long. Because of a one-to-one correspondence between the Prognosis and Root Disease tree lists, the Prognosis tree lists can never contain more than 500 records when using the root disease extension. Compression of the tree lists occurs whenever the number of records exceeds 500. This keyword allows the user to specify the maximum size of the tree lists for the scenario to be between one and 500 records. Compression will occur automatically whenever the tree list length is about to exceed (because of new regeneration) the user-defined maximum. There is a tradeoff to be aware of in that a shorter tree list is quicker to process but compression is expensive. It is advisable to compress the tree list to about 200 elements if a large number, near 500, tree records are read in and regeneration is to occur. This will minimize the number of times the compression routine will have to be called. Two precautions: (1) Be sure to include the NOTRIPLE Prognosis keyword to avoid immediately undoing the effect of the RRCOMP action, and (2) be sure not to introduce an RRCOMP action between the time of a harvest and the subsequent timing of the CARRY keyword.

Field 1: The maximum size of the tree list. The tree list is compressed to this number whenever its length approaches this number. An error message will appear if the value of field 1 is blank or is greater than 500 and the maximum size of the tree list will be set to 150 records.

DEFAULT: 150 records.

RRJUMP — Root disease spreads through trees around the edge of centers when the stand is thinned or clearcut. This keyword allows the user to specify the extent to which root disease will expand outward when centers are cut.

Field 1: This field contains the number of root-system diameters by which the centers will expand upon cutting. The model computes the average root system diameter of all trees in the stand, and the centers will move out this distance multiplied by the value contained in parameter field.

DEFAULT: Centers will expand one mean root radius upon cutting.

RRMINK — It is assumed that modifiers of the mortality and infection dynamics of trees infected with either *Armillaria* or *P. weirii* are effective at all tree sizes. This keyword allows the user to relax this assumption (see also the TTDMULT keyword and fig. 3).

Field 1: This field contains a time-to-death below which the modifiers specified by the TTDMULT keyword do not influence mortality and infection dynamics for trees infected by *Armillaria*. This field should contain a value. If it is blank, the minimum time to death is set to 0 years.

Field 2: This field contains a time-to-death below which the modifiers specified by the TTDMULT keyword do not influence mortality and infection dynamics for trees infected by *P. weirii*. This field should contain a value. If it is blank, the minimum time to death is set to 0 years.

DEFAULT: The time to death below which the modifiers do not influence mortality and infection dynamics is 0 inches for both *Armillaria* and *P. weirii*.

RSEED — This keyword allows the user to change the seed value used in starting the model random number generators. The random number generators are used in the dynamic simulation of spread rate, as well as in the dynamics of infection inside root disease centers.

Field 1: The new seed value. This can be any positive integer number less than the maximum number allowed on the particular computer. The default value is 855998726.

SPREAD — Specifies the type of spread model to be simulated (static or dynamic).

Field 1: Contains either a 0 or 1. If 0 is entered or is left blank, a static spread model is assumed and an entry in field 2 will be read, specifying the fixed annual spread rate. If 1 is entered, dynamic spread model is used.

Field 2: The fixed annual spread rate. This field is only examined if field 1 is blank or contains 0.

DEFAULT: Static spread model, with a spread rate of 1.0 ft per year.

TDISTN — Spread of root disease between trees depends on the spatial distribution of trees in the stand. The distribution can be random or gridded, as in a plantation. This keyword allows the user to specify the initial tree distribution and the tree distribution after some point in the simulation.

Field 1: This field contains the year in which the distribution will change from that specified in field 2 to the other. This is particularly useful when, for example, a stand is to be cut and turned into a plantation.

Field 2: This field is used to specify the current tree distribution. If field 2 is blank or contains a 0, the tree distribution is assumed to be random. If field 2 contains a 1, the tree distribution is set to regular spacing. All other entries in the parameter field are ignored and the default, a random distribution, is used.

Field 3: This field contains the standard deviation about the mean distance between trees in a regular, or lattice, distribution. This is useful in those cases when a stand is to be established with planting, but natural regeneration is allowed in the stand.

DEFAULT: The tree distribution is assumed to be random.

TTDMULT — This keyword allows the user to change the time-to-death multipliers for root disease mortality. These multipliers permit the user to vary the time-to-death for each tree species. (See also the RRMINK keyword and fig. 3.)

Field 1: This field contains a year in which the time-to-death multipliers modified with this keyword are to take effect. This allows the user to change these parameters once during the simulation. The user must put the year in field 1 on all TTDMULT keywords that refer to time-to-death multipliers changed at some point during the simulation. The year in which the time-to-death multipliers are changed is the date specified on the last TTDMULT keyword that has a year in field 1.

Field 2: This field defines for which type of root disease the multipliers are to be specified. A value of 1 specifies *Armillaria*, while a value of 2 specifies *P. weirii*. Any other value entered on this line will cause an error message to be printed and the *Armillaria* type to be assumed. However, if the disease specified in this field differs from that specified by the RRTYPE keyword, this keyword will be ignored.

Field 3: The value entered in this field, if between 1 and 11 inclusive, specifies that a single multiplier is to be changed and indicates the tree species index to be changed. Any other value indicates that all multipliers are to be changed and a supplemental record is to be provided with Format 11F5.2 for the new multipliers. Indices for tree species are given in the rightmost column of table 4 of Wykoff and others (1982).

Field 4: This field is only examined if field 3 has a value between 1 and 11 inclusive. It contains the new multiplier for the tree species indexed in field 3.

Supplemental Records

A supplemental record is expected if all multipliers are to be changed (field 3 is not a number between 1 and 11 inclusive). Format for this supplemental record is 11F5.2.

DEFAULT:

Species abbrev.	WP	L	DF	GF	WH	C	LP	S	AF	PP	OTH
Species index	1	2	3	4	5	6	7	8	9	10	11
Armillaria	1.8	2.0	1.0	0.75	0.9	1.2	1.8	1.1	0.75	1.8	0.9
P. weirii	3.0	1.5	1.0	1.0	1.5	10.	3.0	1.1	1.0	3.0	1.5

APPENDIX III—KEYWORD SUMMARY AND DEFAULT VALUES

This summary lists all the keywords and their associated parameter fields for the Root Disease Model. Default values exist for all program options. Keywords need only be used if the desired action differs from the default action. Page number of detailed description of each keyword appears in parentheses beneath the keyword.

Summary of Keyword Specific to Root Disease Model Extension

Keyword	Parameter fields 1	2	3	4	5	6
Program execution options						
COMMENT (10)	Supplemental records, as many as desired until END in the first 3 columns is read.					
END (11)						
RRDOUT (10)	logical unit number for detailed output					
RRECHO (10)	logical unit number for machine readable output					
RRIN (10)						
Root disease inventory options						
PLREAD (14)	Supplemental Records: 1 record for each subplot in disease center. Subplot number in I4 format corresponding to the subplot identifier on the tree records. A subplot identifier of –999 indicates end of subplot supplemental records.					
RRINIT (12)	type of root disease initialization (random/fixed)	no centers in stand	number infected trees per acre in disease centers	number uninfected trees per acre in disease centers	proportion of root systems colonized	total area in root disease centers (acres)
	Supplemental Records, if initialization is fixed, 1 record for each center noted in field 2 of RRINIT keyword, (3F7.1) X-coordinate of center, Y-coordinate of center, radius of center.					
RRTREIN (14)						
RRTYPE (12)	root disease type					
SAREA (12)	stand area (acres)					
STREAD (15)	Supplemental records containing following information are needed for STREAD keyword, (I4,2F6.1) tree species, stump diameter, number of stumps. –999 in first 4 columns signals end of plot information.					

(con.)

Keyword	Parameter fields 1	2	3	4	5	6
Root disease management options						
PSTUMP (16)	year of stump pushing	proportion of stumps removed	minimum stump diameter to be removed			
Model modification options						
BBTYPE1 (16)	first year beetle infestation can occur	tree species to infest	minimum DBH to infest	minimum No. of eligible stems	proportion of eligible stems killed	
BBTYPE2 (17)	first year beetle infestation can occur	tree species to infest	minimum DBH to infest	minimum No. of eligible stems	proportion of eligible stems killed	
BBTYPE3 (17)	first year beetle infestation can occur	tree species to infest	minimum DBH to infest	minimum No. of eligible stems	proportion of eligible stems killed	minimum proporation of roots infected in eligible stems
CARRY (40)	type of carryover (static or dynamic)	No. growth cycles after stand entry that carryover model is called	(static model) probability of forming new centers (dynamic model) minimum spread rate	(static model) number of new centers to form (dynamic model) not used		
INFKILL (40)	tree species to modify	root infection at death				
	Supplemental records, if field 1 of INFKILL keyword is ≤0 or >11, all species changed, (11F5.2) Root infection at death for all species.					
INFMULT (41)	year multiplier takes effect	root disease type	tree species to modify	species multiplier		
	Supplemental records, if field 3 of INFMULT keyword is ≤0 or >11, all species changed, (11F5.2) Probabilities of infection for all species.					
INOCSPAN (42)	years for *Armillaria*	years for *P. weirii*				
RRCOMP (42)	No. records to which tree list is compressed					

(con.)

	Parameter fields					
Keyword	1	2	3	4	5	6
Model modification options (Con.)						
RRJUMP (43)	No. of root-system diameters to expand centers after cut					
RRMINK (43)	years to death for *Armillaria*	years to death for *P. weirii*				
RSEED (43)	alternative seed value for random number generators					
SPREAD (43)	type of spread (static or dynamic)	annual spread rate (for static spread)				
TDISTN (44)	year in which tree spatial distribution changes to other type	tree spatial distribution of initial stand (random or uniform)	standard deviation of uniform distribution			
TTDMULT (44)	year multiplier takes effect	root disease type	tree species to modify	species multiplier		
	Supplemental records, if field 3 of TTDMULT keyword is ≤0 or >11, all species changed, (11F5.2) Time-to-death multipliers for all species.					
WINDTHR (18)	first year windthrow can occur	proportion of eligible stems to windthrow	minimum No. of eligible stems necessary for windthrow event			

Default values for Keywords;

COMMENT, END, PLREAD, and RRIN have no defaults

Keyword	Default values by field					
	Field 1	Field 2	Field 3	Field 4	Field 5	Field 6
BBTYPE1	YYYY[a]	7[b]	8.0	10.0	0.85	—
BBTYPE2	YYYY[a]	3[b]	10.0	10.0	0.88	—
BBTYPE3	YYYY[a]	4[b]	10.0	10.0	0.88	0.30
CARRY	0	4	1.0[c]	3.0[d]	—	—
INFKILL	1	—[e]	—	—	—	—
INFMULT	YYYY[a]	1	—[f]	—	—	—
INOCSPAN	0	20	—	—	—	—
PSTUMP	YYYY[a]	1.0[g]	0.0	—	—	—
RRCOMP	150	—	—	—	—	—
RRDOUT	22	—	—	—	—	—
RRECHO	24	—	—	—	—	—
RRINIT	0	20[h]	0.5[i]	0.5[i]	0.1[g]	25
RRJUMP	1.0	—	—	—	—	—
RRMINK	0	0	—	—	—	—
RRTREIN	(Keyword has no parameter fields)					
RRTYPE	1	—	—	—	—	—
RSEED	855998726	—	—	—	—	—
SAREA	100	—	—	—	—	—
SPREAD	0	1.0	—	—	—	—
STREAD	(Keyword has no parameter fields)					
TDISTN	YYYY[a]	0	—	—	—	—
TTDMULT	YYYY[a]	1	—[j]	—	—	—
WINDTHR	YYYY[a]	0.0[g]	0.0[g]	—	—	—

[a]The four-digit YYYY is specified as a calendar year.

[b]The tree species value must be a number between 1 through 11, inclusive, which is the Prognosis tree species index.

[c]If field 1 = 0, then a static carryover model is invoked with a default of 1.0 in field 3. If field 3 is specified by the user, the value must be a number between 0.0 and 1.0, inclusive. If field 1 = 1, then the dynamic carryover model is invoked with a default of 0.0 feet per year in field 3 as a minimum spread rate.

[d]This field is only used if field 1 = 0. The number of new centers must be between 1 through 100, inclusive.

[e]A supplemental record is expected if the proportion of roots infected at death are to be changed for all species (value other than 1 through 11 inclusive, entered in field 1). Format for this supplemental record is 11F5.2.

[f]A supplemental record is expected if the probabilities of infection are to be changed for all species (value other than 1 through 11 inclusive, entered in field 2). Format for this supplemental record is 11F5.2.

[g]The value must be a number between 0.0 and 1.0, inclusive.

[h]The number of root disease centers must be between 1 and 100, inclusive.

[i]If RRTREIN is not present, fields 3 and 4 will default to 0.5 of average stand density.

[j]Supplemental record is expected if all multipliers are to be changed (value other than 1 through 11, inclusive, entered in field 2). Format for this supplemental record is 11F5.2.

Stage, Albert R.; Shaw, Charles G., III; Marsden, Michael A.; Byler, James W.; Renner, David L.; Eav, Bov B.; McNamee, Peter J.; Sutherland, Glenn D.; Webb, Timothy M. 1990. User's manual for Western Root Disease Model. Gen. Tech. Rep. INT-267. Ogden, UT: U. S. Department of Agriculture, Forest Service, Intermountain Research Station. 49 p.

Effects of pathogenic *Armillaria* spp. or *Phellinus weirii* on stand dynamics are represented by the Western Root Disease Model. This model, which operates in conjunction with the Prognosis Model for Stand Development, can be used to evaluate effects on stand generation and growth of a wide assortment of silvicultural practices, including stump removal for disease reduction. This publication contains model applications, a brief description of how the model is formulated, and documentation of the keyword procedures for using the model.

KEYWORDS: *Armillaria, Phellinus weirii,* Prognosis Model, bark beetles, windthrow

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General Technical
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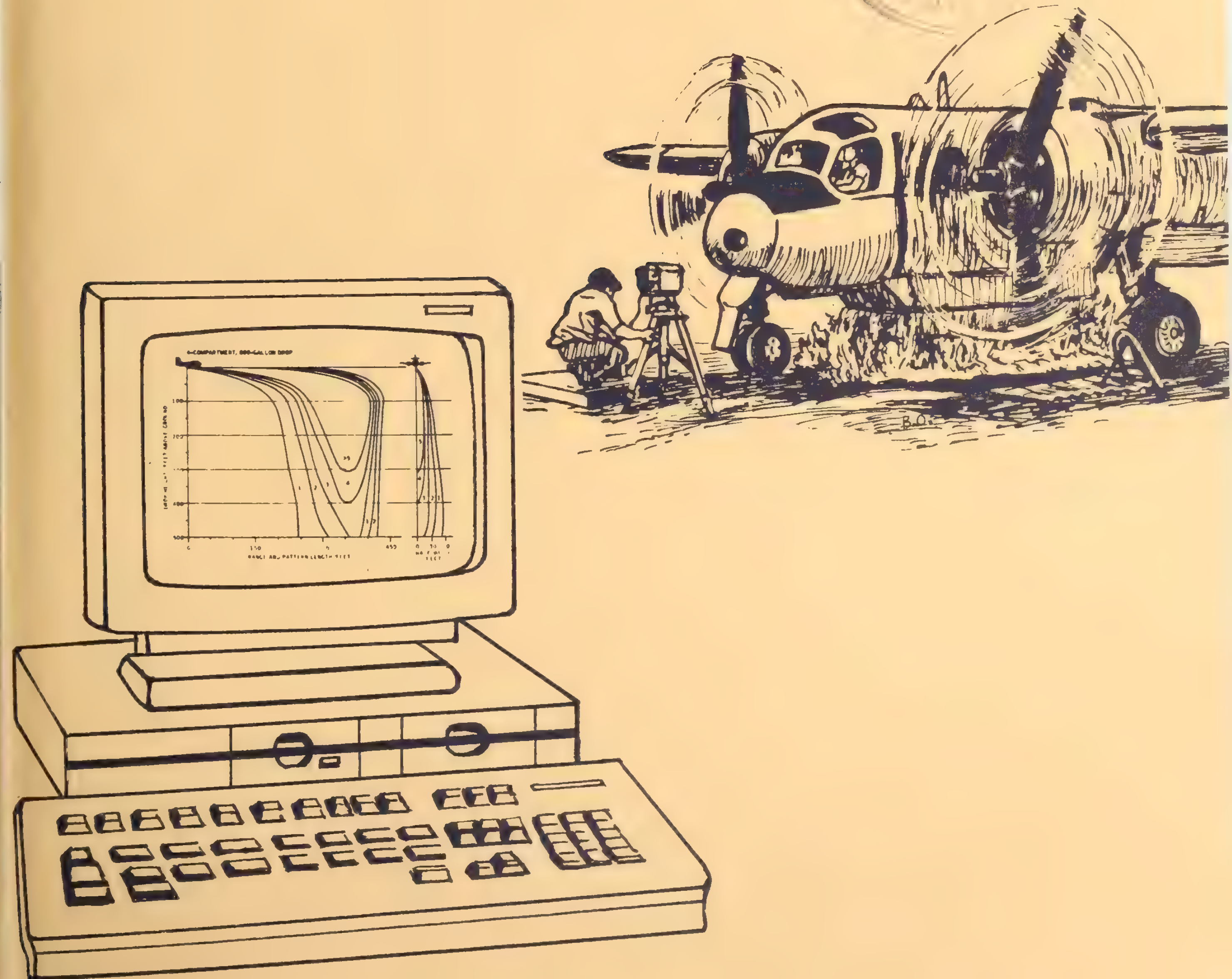
Developing Air Tanker Performance Guidelines

Charles W. George
Gregg M. Johnson



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CONTENTS

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Developing Air Tanker Performance Guides

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INTRODUCTION

Since the first operational airtanker drops in 1956, many different aircraft, ranging from agricultural spray planes to modern military transports, have been used as airtankers. The tank and gating systems of these aircraft are of many different designs, with differing capabilities. In 1969, the Forest Service initiated research studies to quantify the capabilities of different tank and gating systems. The studies entailed the dropping of retardant and/or water over a sampling grid and determining the ground pattern under a variety of conditions: tank configuration, door sequencing speed, drop height, retardant type, relative humidity, temperature, windspeed, and direction (George 1975; George and Blakely 1973). Using these data, Honeywell Corporation, under contract to the Forest Service, developed a pattern simulation model whose primary variable was the flow history from the individual systems (Swanson and others 1975). The rough model used flow history derived from motion pictures of airborne airtanker drops. The model was refined through the use of accurately measured flow data. (Swanson and others 1977). A BASIC listing of the model is included as appendix A.

Information from the refined model (PATSIM) suggested that proper tank design could be used to produce drop patterns that would be effective for nearly any fuel-fire condition. In order to define the tank parameters and to fine-tune and validate PATSIM, an experimental tank and gating system (ETAGS) was designed, installed in a Forest Service P2V-5 airtanker, and drop-tested over a sampling grid. The ETAGS was designed so that tank and gating parameters, including load size, fluid head height, door opening length-to-width ratio, compartment separation, door-opening area, and fluid flow rates could be examined along with flight parameters (drop height and speed). The knowledge gained from the ETAGS test was used to refine PATSIM to its final form. The accuracy of PATSIM was proven for tanks with "average" length-to-width ratios; however, for tanks with an extreme length-to-width ratio PATSIM showed a strong tendency to underpredict the length of the ground pattern and overpredict the retardant coverage concentrations (Swanson and others 1978).

About 90 percent of the current airtankers have been static-tested and user guidelines produced. New airtankers are tested as part of Interagency Airtanker Board (IATB) approval process. PATSIM is also used as a tool to aid in the design of new tank and gating systems and for evaluating flow-rate modifications to enable airtankers to meet improved and more flexible standards set by the IATB (USDA FS 1987).

GUIDELINE DEVELOPMENT SEQUENCE

The first step in the generation of airtanker performance guidelines is to quantify the flow of water/retardant from the airtanker delivery system for all possible drop configurations. This is accomplished by static testing airtankers to determine flow history, door-opening rate, and internal tank pressure according to the methods set forth by Blakely, George, and Johnson (1982). The representative flow rates for each compartment and drop type are selected and used as input to PATSIM (the airtanker ground pattern response model) and PATADD (adjunct to PATSIM for reducing data from dissimilar compartments in a tanking system). The ground pattern data output by PATSIM/PATADD is smoothed, tabulated, plotted (using computer programs developed at the Intermountain Fire Sciences Laboratory and written in BASIC), and assembled into a standard guideline format. A schematic of the steps followed in producing airtanker performance guidelines is shown in figure 1.

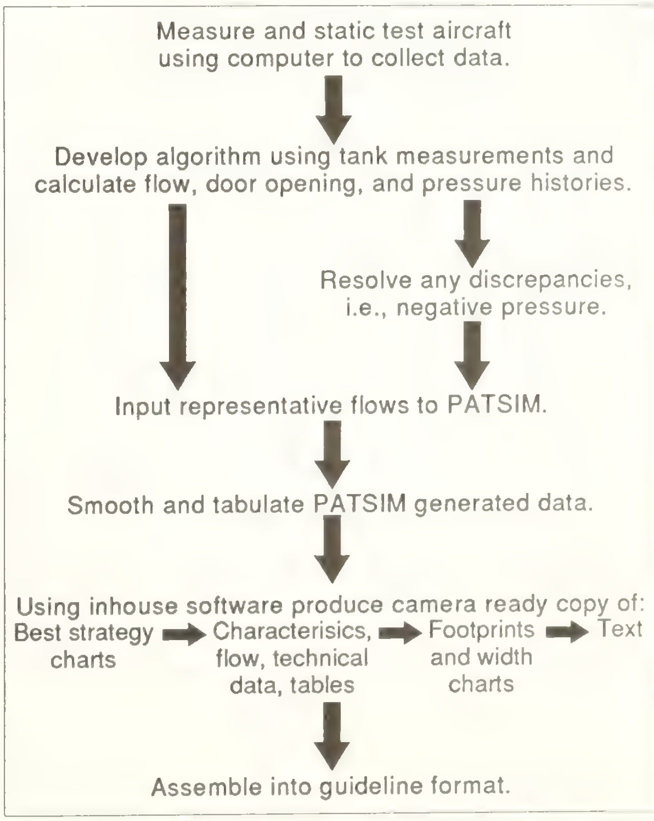


Figure 1—Guideline production sequence.

OPERATION OF PATSIM/PATADD MODELS

The simulation program (PATSIM) uses an algorithm consisting of four distinct parts:

1. Generation of a marginal downrange distribution (percent of retardant delivered in each foot of pattern length) from flow rate and aircraft velocity.
2. Development of the marginal crossrange distribution as a function of altitude and retardant type.
3. Calculation of the ground response pattern from the distributions.
4. Summarization of the ground response pattern as a scaled pattern schematic of the coverage level distribution on the ground and the gallons, area, and lengths associated with various coverage levels.

The generation of the marginal range distribution, though empirically derived, has its analogy in the physical process of the breakup of the mass of retardant released from an airtanker (fig. 2). The door opening shapes the emerging fluid (phase A), which is subject to small particle stripping, drag deceleration, and amplifying instabilities of two types—Taylor instabilities on the front surface and Helmholtz instabilities on the side surfaces. The small particles stripped from the retardant are a relatively insignificant portion of the total mass. The emerging liquid mass also expands to the sides and becomes shorter as lateral flow replaces some of the deceleration (phase B). The amplitude of the Taylor instabilities increases until air pressure on the front surface causes breakup and final particle size distribution (phases C and D). Rheological properties and airspeed establish the time to breakup and final particle size.

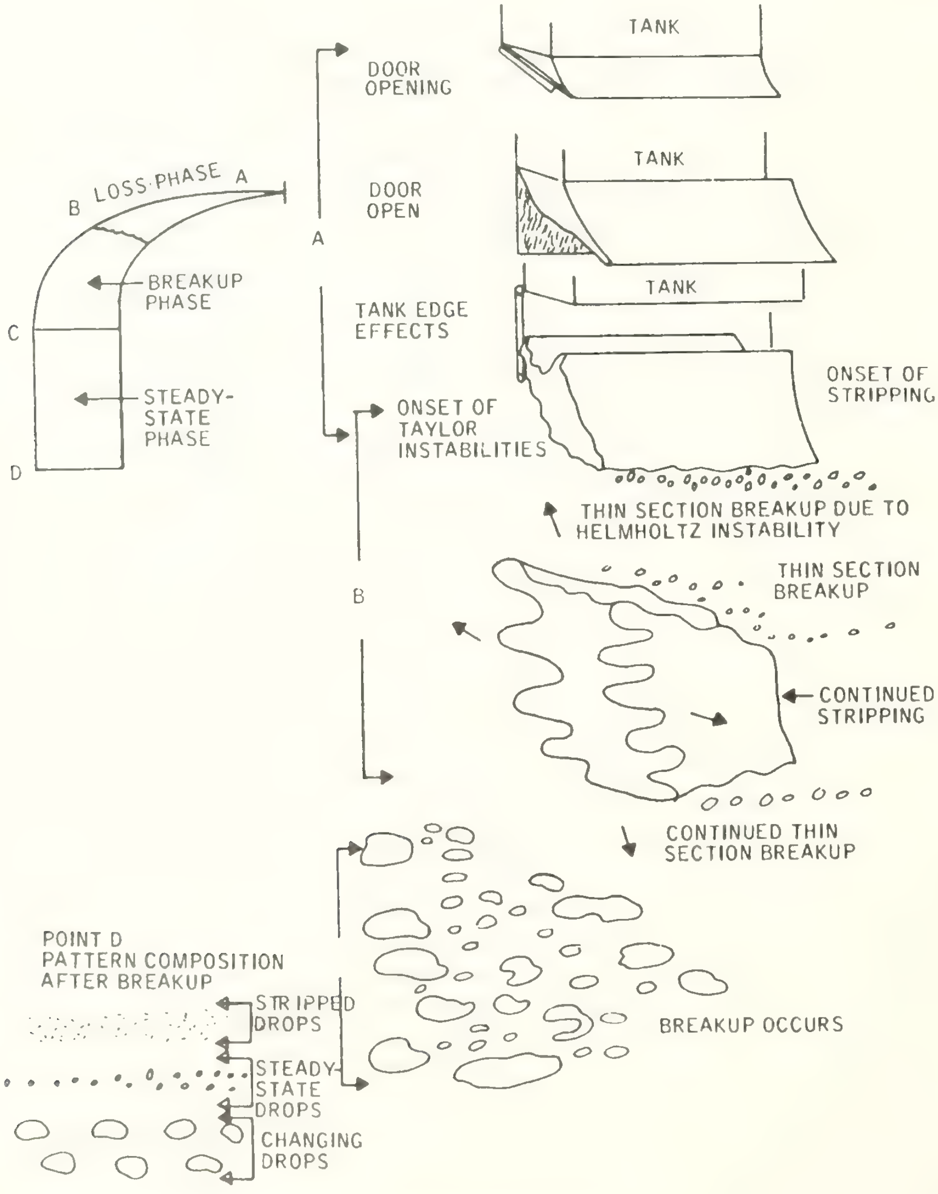


Figure 2—Schematic representation of the breakup process.

In the case of one or more compartments located aft of, and released at the same time as, a front compartment, the forward released retardant acts as a wind shield for the aft releases, thereby delaying the breakup until the forward release is nearly at its final particle size. At that point, the aft release passes through the retardant cloud of the forward release.

The algorithm first calculates the range marginal distribution by breaking the volume discharged from the tank into small increments based on time and calculating each one's distribution at the ground level. The distributions are summed to produce the final range marginal distribution.

To develop the range marginal distribution into an isopleth, a normal crossrange marginal is assumed and is calculated on the basis of altitude and retardant type. An amount of retardant lost to evaporation and small particle drift is discarded. A percentage of the remaining retardant (also a function of altitude and retardant type) is distributed over an elliptical area. This quantity represents the fringe of the pattern, contains low coverage levels, and is most subject to wind drift. The remaining 70-90 percent of the retardant is distributed as a normal distribution. The sum of these two sections produces the simulated ground pattern (fig. 3).

In order to calculate the most efficient time interval between single tank releases that make up a trail drop, a subroutine (PATADD) is used. PATADD shifts and overlays the simulated patterns, determining the time interval between door releases for each coverage level that produces the longest length of retardant pattern for that coverage level.

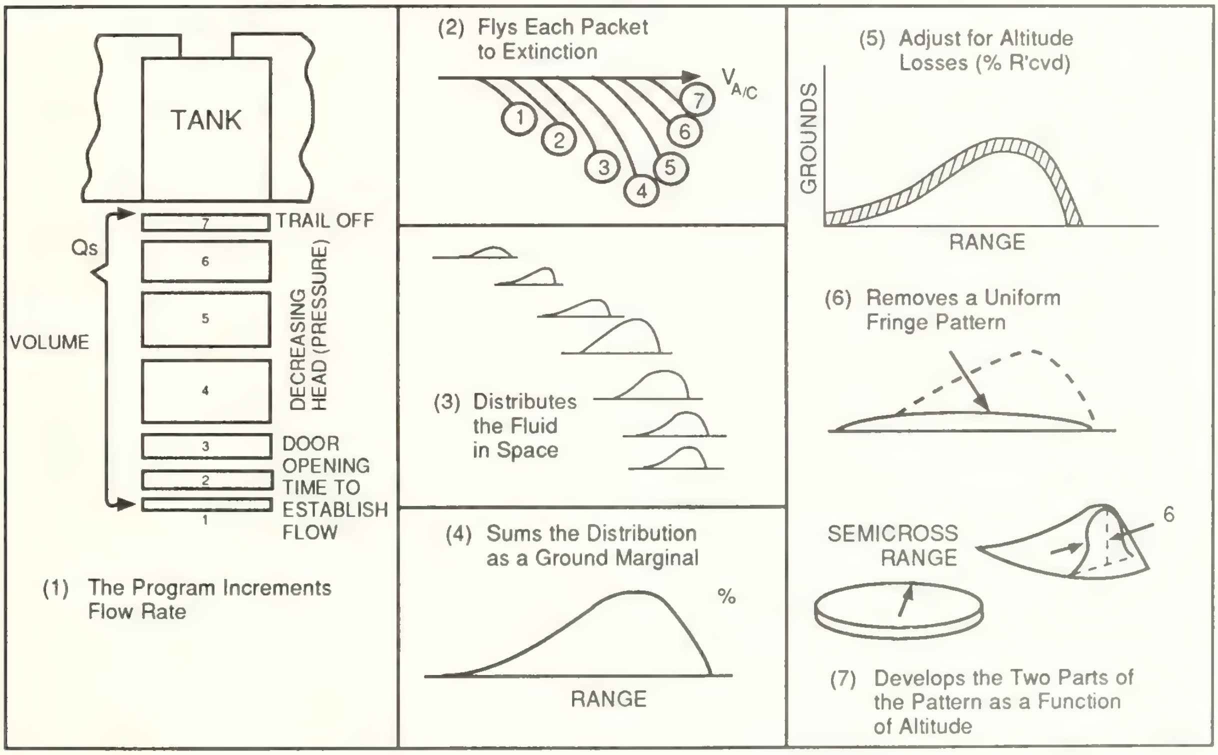


Figure 3—Simulation overview (Swanson and others 1975).

Inputs to PATSIM Model

The simulation is designed to be used in two general modes: (1) the tank is described geometrically and the flow rate calculated and (2) the flow rate is determined experimentally and input directly to the simulation. The latter has proven to be the most accurate and is used to produce the guidelines. Experience has shown that door-opening rate (which is reflected in the flow rate) and ejection velocity from the tank have little effect on the accuracy of the prediction and are therefore not used.

The inputs used in PATSIM for guideline production are: (1) experimental tank flow data; (2) quantity vs. time; (3) number of flow data entries; (4) total gallons in tank; (5) number of tanks released; (6) retardant type; (7) aircraft speed; (8) aircraft altitude; (9) ADD, a flag set if trail drops are to be calculated using the PATADD subroutine (table 1). A sample input is contained in appendix B.

PATSIM Modification

The PATSIM predicts ground response patterns satisfactorily for most airtankers in use. But the ETAGS study showed that modifications to PATSIM were necessary for a tank with very clean exit geometry. One particular tank, installed in a Conair Aviation, Ltd., DC-6, had compartments that were smooth, with no reinforcing members or door edges that could cause turbulence in the exiting retardant. Using data for actual ground response obtained over a test grid, it was found that an erosion constant K1 and a shape factor DELZ need adjustment to correctly predict the down range marginal. Similarly, SIGMA, the shape factor for the normal distribution in the cross range marginal also needed adjustment.

After using various values for these constants and comparing the results from PATSIM with the actual pattern responses from drop tests, it was found that the three constants worked best for generally smooth tanks when converted to variables that were a function of drop height and the number of compartments dropped. Only one such tank has been tested. PATSIM was developed from ground response data for tanks that would impart turbulence to the exiting retardant due to internal bracing, door sills, and other features.

Program Output

The program output consists of (1) a report of input data; (2) detailed pattern plot; (3) contour interval summaries; (4) a scaled pattern plot; (5) pattern length data; and (6) PATADD output, if selected. A sample output is shown in appendix B.

INPUT DATA

An echo of input data for confirmation of data and identification of the pattern.

DETAILED PATTERN PLOT

A printout of the pattern on a 28-column by 56-row unscaled array. The distance between columns is 15 feet and between rows is 30 feet.

CONTOUR INTERVAL SUMMARIES

1. Table of the amounts of retardant in each coverage level (gallons per 100 square feet) 0.0-0.5, 0.6-1.0, 1.1-2.0, 2.1-3.0, 3.1-4.0, 4.1-5.0, 5.1-6.0, 6.1-7.0, 7.1-8.0, 8.1-9.0, 9.1-10.0, and greater than 10 gallons.
2. Total amount of retardant on the grid in gallons and the percent of total gallons dropped that is recovered.
3. The area in square feet covered tabulated by the coverage levels and the total area covered.
4. A scaled pattern schematic with listed coverage levels and a table of pattern lengths tabulated by coverage levels.
5. If the PATADD option was selected, a table of the maximum length of the patterns for multiple tank drops and the delay between releases required to obtain the patterns at coverage levels equal to or greater than 0.5, 1.0, 2.0, 3.0, 4.0, 6.0, 8.0, 10.0 gallons per 100 square feet (gpc).

Table 1—PATSIM inputs

Variable No.	Name	Description
17	GALI	Total volume of tank in gallons
18	CFLAG	Number of tanks released
24	RDQV	Flag to select option for entry of experimental flow data also the number of entries in the flow data table
45	RFLAG	Retardant type—1 = gum-thickened; 2 = waterlike
51	VACI	Aircraft speed
2	ALT	Aircraft altitude
53	ADD	Flag to select PATADD
*	*	A code in columns 1–8 indicating the number of patterns to add

GUIDELINE PRODUCTION

Selection of Inputs

The basic input will be the volume discharged as a function of time (flow) for *each compartment of the tank system to be analyzed*. For example, a six-tank system might have its six compartments in a row across the tank, with the two outside tanks differing from the four inner tanks (fig. 4). Flows from the outer and inner tanks would be expected to differ even though their volumes are nearly identical. It is also possible that due to capacities of hydraulic or pneumatic door-opening systems the doors of some compartments may open at different rates than others. This produces different flows from the same compartment when the compartment is released alone or in conjunction with one or more other compartments. The static test data (flow rates, door-opening time, and tank pressure) should include tests of all geometrically dissimilar tanks under all possible release conditions. In the case of the tank in figure 5, if each compartment opened at the same rate for 1, 2, 3, or 6 compartments released at a time, two different flows (outer and inner compartments) would be needed to characterize the tank. If the flows had been different for one compartment at a time and six compartments at a time, four different flows would be required. The best method of comparing flows is to plot volume discharged vs. time from static tests for any compartments that could be different (fig. 5). In cases where a difference is not obvious, PATSIM can be applied using the flow data to be compared as inputs to determine if pattern differences exist.

In the case of inadequate venting of a compartment, the flow may appear to halt or slow momentarily before continuing. Because flow measurements are taken by use of a float on the surface of the liquid, it would appear that the flow out of the tank was halted. But, examination of high-speed films and testing with a transparent tube showed that the tank was still emptying from the bottom. In this case, the flow must be synthesized. The best approximation of flow is to extrapolate the volume discharged to an end point where the float begins to free-fall (fig. 5). With undervented tanks, the flow and thus the ground pattern can exhibit undesirable effects such as thinning or gaps in coverage. Whenever possible, adjustable venting systems are used and venting is fixed after optimum flow rate is attained. When venting adjustments cannot be adjusted at the time of the test, vent size is set on the basis of experience.

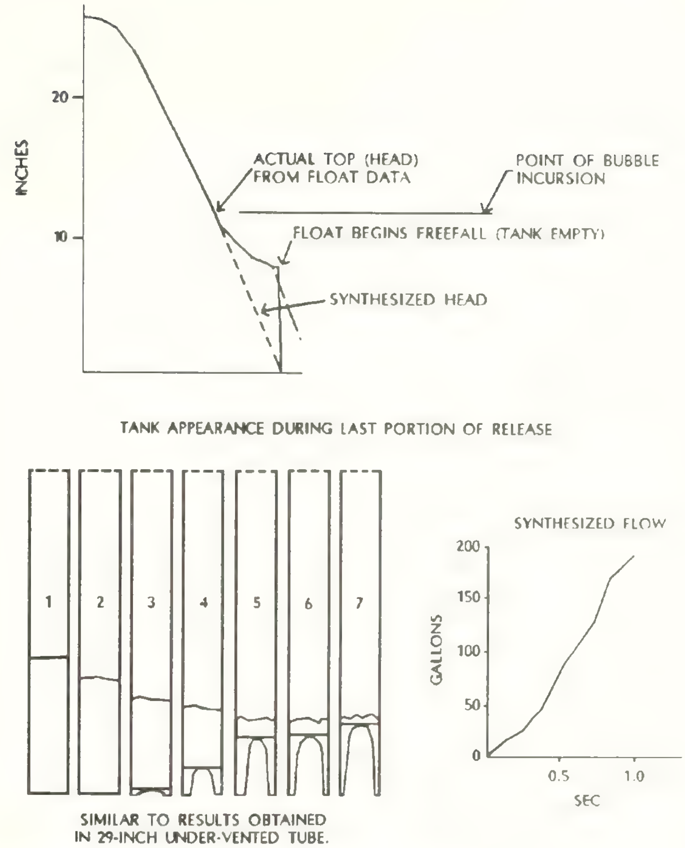


Figure 5—Method of inferring final stages of flow from an undervented tank.

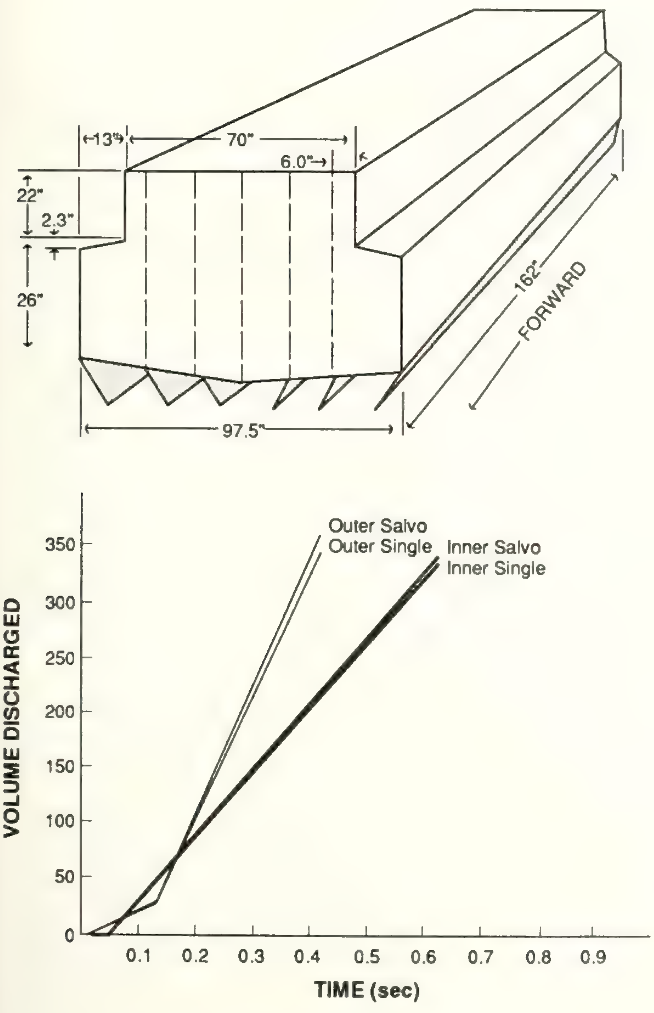


Figure 4—P2V-7 tank and flow rates.

After evaluation of the flow data, typical flows are selected for use in the computer simulation of drop patterns. If there is a large amount of variation in flows within replicate static tests, a mean flow should be selected. But the extremes of flow data should also be evaluated using the simulation to assess the sensitivity of these variations on guideline conclusions. In most cases, these variations are minor.

The computer simulations are run at a midrange aircraft velocity taken from the velocities listed in the approved supplemental flight certificate when used as an airtanker. This range is typically narrow (110-135kt) and ground pattern effects are relatively small compared to drop height, drop configuration, or release intervals. Examination of the sensitivity of patterns to aircraft velocity suggests that differences due to velocity over the range of typical drops is less than might be expected. Higher velocities generally reduce peak coverage and increase pattern length at low coverage levels. Slower aircraft velocities tend to increase maximum coverage levels at the expense of the lower coverage pattern lengths. The uncertainty of true airspeed at the time of the drop is generally less than the magnitude of pattern change resulting from the selection of a specific aircraft velocity. Performance in an actual drop may be somewhat better, but seldom worse than the simulation shown in the guides. Level flight over flat terrain is assumed due to the very large number of graphs needed to show the effects of sloping terrain. This effect can be approximated by drawing a sloping line through the pattern footprint graphs in the completed guide.

The schedule of PATSIM runs should include runs for each different type of compartment/drop at 100-foot intervals between 100 and 500 feet. Where identical compartments are released sequentially (trail drop), the PATADD option should be exercised. Because the PATADD option will add only identical compartments, a trail drop where nonidentical compartments are released requires the application of the separate PATSUM Program. This allows the input of two or more patterns for nonidentical compartments obtained from previous PATSIM runs.

Appendix B contains the data from the computer simulation which consists of:

1. Detailed pattern plots used in generating footprints and for entry into the PATSUM routine for summation of dissimilar trail drops.
2. Pattern area, length, and volumes. The remainder is for inspection only.
3. Maximum line length/tank sequence tables from PATADD. These are summarized and plotted to yield best strategy charts and are presented in tabular form in the guides. (PATSUM is used for dissimilar tanks.)

Complete instructions for PATSIM use may be found in "Development of User Guidelines for Selected Retardant Aircraft" (Swanson and others 1977).

Detailed Guideline Preparation

A sample guideline is included as appendix C. At the beginning of the guide is a one-page summary of the aircraft/tank characteristics, together with an outline drawing of the aircraft, a detailed isometric tank drawing, a summary table of tank system characteristics, and a narrative summary of the aircraft/tank system performance.

The narrative summary contains an aircraft description and tank options, characteristics of the tank and how they control the pattern, a summary of the best strategy charts, noting the most useful drop methods, ground safety precautions, and any unique characteristics.

The characteristics chart contains the total tank capacity, the increment contained in each separately releasable compartment, evacuation time (total time to empty), the average flow rate (capacity of tank released/evacuation time), and peak flow rate. Peak flow rate is calculated from the flow data used as input to the simulation as:

$$\text{peak flow rate} = \text{maximum value of } \frac{DQ}{DT} \text{ from measured flow data}$$

when DQ is the volume in gallons released during time interval DT.

Pattern Coverage Characteristics (Footprints)

Pattern footprints display pattern performance as a continuous function of drop height for each combination of simultaneously released tanks, door option (if applicable), and each retardant type. The procedure explained below is illustrated in figure 6. Pattern length and initial down-range impact for each coverage level are extracted from the central pattern section (columns 14 or 15) of the detailed pattern plots. All coverage levels are linearly interpolated to the nearest foot of pattern length. At zero drop height, a length representing aircraft travel during the time of tank evacuation is calculated to be used as the end point for the plotted footprints (speed in feet per second evacuation time). These points are plotted for each coverage level 1 through 5 and a smooth curve drawn to form the footprints. Footprint half-width for each coverage level/drop height is found by averaging the width from each row of the detailed pattern plots. These half-widths are plotted and smoothed similarly to the pattern footprints. The values for length, downrange impact point, and width are calculated and tabulated using the summary program LDRWIDTH; the footprint is smoothed using the SMOOTHFOOT program, and final plots are made using FINALFOOT.

Scaled silhouettes of the side and head-on views of the aircraft are placed above the footprint and half-width graphs to indicate the relationships of the graphs to aircraft flight direction. This process is accomplished using several BASIC programs.

Also included on the pages with pattern footprints are a brief set of instructions for use of pattern footprints and a table of recommended coverage levels for different fuel types (Deeming 1972; Rothermel and Philpot 1974). LEDRWIDTH, SMOOTHFOOT, and FINALFOOT are listed in appendix D.

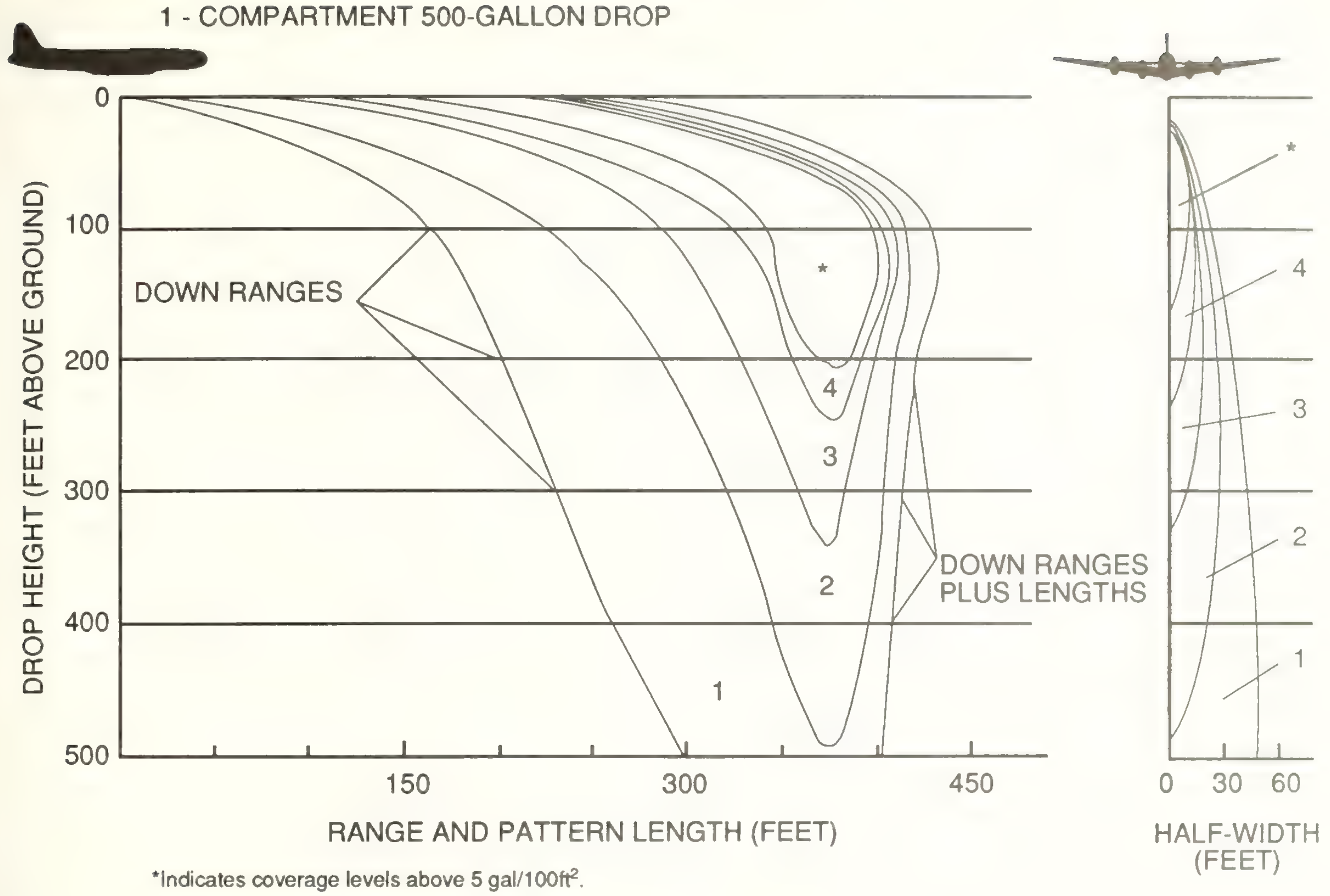


Figure 6—Footprint.

Best Strategy Charts

The section of the guide containing the best strategy charts is preceded by a page of instructions for their use. Best strategy charts are graphic summaries of selected pattern information generated by using the PATADD option to PATSIM (fig. 7). These summaries are also tabulated and presented following the best strategy charts. Best strategy charts are generated for coverage levels 1 through 4 for waterlike and gum-thickened retardants. For a selected coverage level and retardant type, the length of line at drop heights of 100 to 500 feet for each possible load fraction are plotted.

For a tank with four identical compartments, there are six possible combinations:

1. Single-compartment release (1Tx1R)
2. Two compartments released simultaneously (2Tx1R)
3. Four compartments released simultaneously (4Tx1R)
4. Two compartments released sequentially (1Tx2R)
5. Four compartments released sequentially (1Tx4R)
6. Two two-compartment sequential releases (2Tx2R)

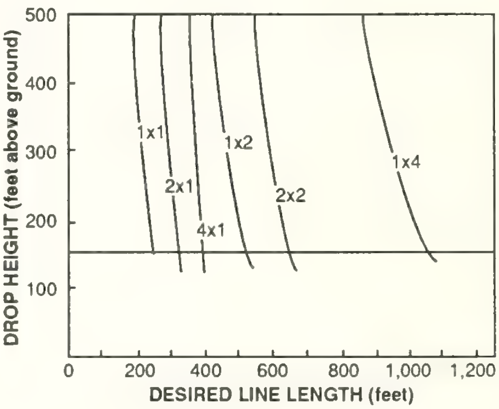
Each of these combinations is regressed, using a standard multiform regression program, and roughly plotted. From this rough plot, the optimum drop for each load size can be selected for the final best trail strategy chart. For example, if the four-compartment in (1Tx4R) produces a longer line length than a four-compartment salvo (4Tx1R), the four-compartment salvo would not be plotted on the final chart (fig. 7) (length and width dimensions for the salvo could be found on the appropriate pattern footprint). Each area is identified with the proper label and a nominal time interval between releases in the case of sequential releases. The proper time interval changes with drop height and airspeed and is reported to 0.1 second. The value of the interval at 200 feet for the drop type in question is chosen as being most representative. A minimum drop height safety limit of 150 feet above ground determined by Forest Service policy is shown on the bottom of the chart.

The accuracy limit curve (Swanson and others 1975) is based on a Honeywell-derived probability of hit for military ordnance and is common to the best strategy charts for all aircraft. It corresponds to a curve defined by setting the probability of hit at 0.6 for no wind and level flight. The curve is drop-height-dependent, indicating the length of line below which a hit is improbable. Because the curve is independent of the pattern width, which is relatively constant for full-door drops, a separate curve is generated for aircraft equipped with a trail door option, which produces a narrower retardant pattern. This arbitrary change simply moves the 300-foot length limit to the 500-foot drop height. Best strategy charts are produced using the BASIC programs: BSPLOT, BESTSTRAT.DAT.

MAXIMUM LINE LENGTHS WITH CORRESPONDING TANK OPENING DELAYS

No. of	0.5 GPC Feet	0.5 GPC Sec	1.0 GPC Feet	1.0 GPC Sec	2.0 GPC Feet	2.0 GPC Sec	3.0 GPC Feet	3.0 GPC Sec	4.0 GPC Feet	4.0 GPC Sec	6.0 GPC Feet	6.0 GPC Sec	8.0 GPC Feet	8.0 GPC Sec	10.0 GPC Feet	10.0 GPC Sec
1	320	0.0	265	0.0	190	0.0	115	0.0	80	0.0	0	0.0	0	0.0	0	0.0
2	665	1.8	560	1.5	420	1.3	310	0.9	225	0.3	125	0.0	80	0.0	50	0.0
4	1335	1.8	1150	1.5	860	1.3	630	0.9	495	0.3	300	0.0	235	0.0	170	0.0

			LEVEL 1				LEVEL 2	
							COV	
			0.5		1.0		2.0	
COMPARTMENTS RELEASED AT A TIME	DROP HT FT	NO.OF PATTERNS	MAX LENGTH (FT)	DELAY (SEC)	MAX LENGTH (FT)	DELAY (SEC)	MAX LENGTH (FT)	DELAY (SEC)
		1	325	0.0	265	0.0	190	0.0
	100	2	665	1.8	560	1.5	420	0.0
		4	1355	1.8	1150	1.5	860	0.0
		1	295	0.0	235	0.0	150	0.0
	200	2	615	1.6	495	1.3	350	0.0
		4	1255	1.6	1015	1.3	735	0.0
		1	280	0.0	215	0.0	115	0.0
ONE	300	2	585	1.6	455	1.2	295	0.0
		4	1195	1.6	935	1.2	625	0.0
		1	275	0.0	205	0.0	95	0.0
	400	2	575	1.5	450	1.2	250	0.0
		4	1175	1.5	930	1.2	550	0.0
		1	265	0.0	195	0		
	500	2	555	1.5	420			
		4	1135	1.5	860			
	100	1	375	0.0	335			
		2	765	2.0	69			
	200	1	370	0.0	3			
		2	750	1.8				



SAFE DROP HEIGHT

DROP TYPE	FEET
1X1	170
2X1	200
4X1	240

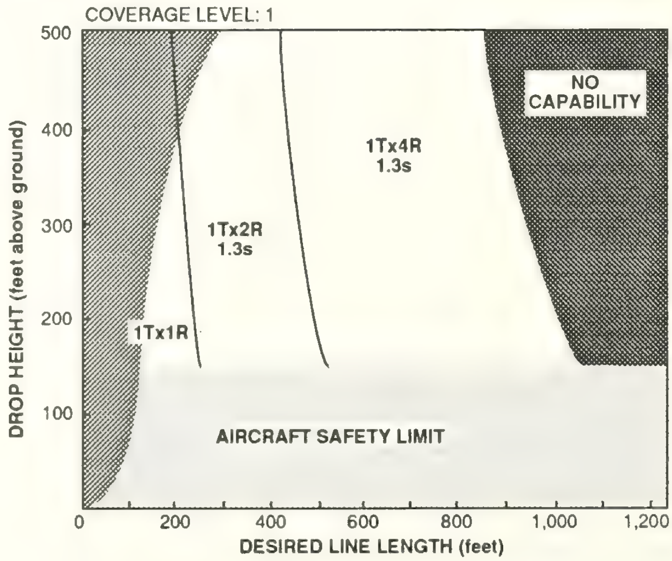


Figure 7—Airtanker characteristics.

Included on the pages containing best strategy charts are a key to the notation on the charts, the table of recommended coverage levels, and a table of ground safety notes. The ground safety table shows for each load type the height below which the retardant mass has lost forward momentum and broken up into droplets, falling as a heavy rain. The equation for these heights was derived from films of test drops and is a function of load size and peak flow rate: Safe drop height = (100.73 + 0.0112 x load size + 0.0202 x peak flow rate) + 50. The arbitrary 50 feet are added as a safety margin.

The remainder of the guide consists of detailed tables of the aircraft's performance transcribed and rearranged from the PATADD subroutine and technical data tables. The technical data tables contain some physical dimensions of the tank system and flow data derived from the static test. These tables potentially enable field personnel to identify tank changes that might affect the guide validity or to judge the similarity to tank systems for which guides are not available. Also included are the date and full identification of the tanker static-tested and any other identical airtankers.

SUMMARY

To date airtanker performance guidelines have been published for most of the airtankers currently being used. These are listed in table 2. An instruction manual, "Airtanker Performance Guides: General Instruction Manual" (Swanson and others 1976) contains detailed instructions on how to read and use airtanker performance guides that contains general information, retardant coverage requirements, pattern footprints, best strategy charts and detailed line length tables.

A need was identified for a small, simple, inexpensive reference that could be used in real-time to identify primary airtanker performance. To fill this need airtanker performance "slide charts" (retardant coverage computers) have been developed along with an instruction manual for their use (George 1981). The retardant coverage computers are a slide-rule-type device that can quickly show the user the length of retardant line and the intertank release interval used for any coverage level (1.0 – 5.0 + gpc), drop height from 100 to 500 feet, and drop type. Retardant coverage computers have been produced for each airtanker covered by performance guides.

As new types of tank and gating systems, whether new aircraft types or systems modified to improve flexibility and performance, come into use, new or updated guides and slide charts should be produced in order to keep this valuable information current and useful.

With the advent of computer-based intervalometers to select drop types and intervals in the newer airtankers, a potential exists to include ground pattern performance data in the intervalometer. The desired coverage level could be selected and the computer could set, or indicate to the air crew, the most effective drop type and interval.

Table 2—List of airtanker performance guidelines

Aero Union tanker B–17	(Request by title)
Gilbertson tanker DC–6B	(Request by title)
CDF/Hemet Valley tanked S2F	PG-1
CDF/Aero Union tanked S2F	PG–2
Ralco tanked PV–2	PG–3
Reeder Tank/Lynch STOL B–26 (tanker 58)	PG–4
Canadair CL–215	PG–5
Evergreen Rosenbalm tanked B–17	PG–6
Globe tanked B–17	PG–7
Black Hills tanked B–17	PG–8
Aero Union tanked DC–4/6/7 (1,800 gal)	PG–9
Aero Union tanked DC–4/6/7 (2,000 gal)	PG–10
Aero Union tanked DC–4/6/7 (2,200 gal)	PG–11
Aero Union tanked DC–4/6/7 (2,400 gal)	PG–12
Aero Union tanked DC–4/6/7 (2,600 gal)	PG–13
Aero Union tanked DC–4/6/7 (2,800 gal)	PG–14
Aero Union tanked DC–4/6/7 (3,000 gal)	PG–15
W.A.I.G. tanked DC–4	PG–16
Hemet Valley/Aero Union tanked C119G–3E	PG–17
Hawkins & Powers tanked C119G–3E	PG–18
Hawkins & Powers tanked PB4Y–2	PG–19
Black Hills/Rosenbalm tanked P2V–5	PG–20
Black Hills/Rosenbalm tanked P2V–7	PG–21
Central Air Services tanked DC–7	PG–22
Transwest tanked DC–7	PG–23
SIS–Q/Rosenbalm tanked DC–6/7 (3,000 gal)	PG–24
C–130 MAFFS	PG–25
Black Hills tanked P2V–5	PG–26
Lynch tanked STOL B–26 (tanker 01)	PG–27
Evergreen P2V–5	PG–29
SIS–Q/Rosenbalm tanked DC–6/7 (2,000 and 2,450 gal)	PG–30
TBM, Inc. F7F	PG–31
Lynch STOL B–26 (tanker 57)	PG–32
Central Air Services DC–4 (2,000 gal)	PG–33
Conair DC–6B	PG–34
TBM, Inc. C–123	PG–35

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Deeming, John E.; Lancaster, James W.; Fosberg, Michael A.; and others. 1972. [rev. 1984]. The national fire-danger rating system. Res. Pap. RM-84. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 165 p.

George, C. W. 1975. Fire retardant ground distribution patterns from the CL-215 air tanker. Res. Pap. INT-165. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 67 p.

George, Charles W. 1981. Determining airtanker delivery performance using a simple slide chart-retardant coverage calculator. Gen. Tech. Rep. INT-113. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 7 p.

George, C. W.; Blakely, A. D. 1973. An evaluation of the drop characteristics and ground distribution patterns of forest fire retardants. Res. Pap. INT-134. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 60 p.

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U.S. Department of Agriculture, Forest Service. 1987. Interagency Airtanker Board, Spec. Rep. 8757 1801. San Dimas, CA: U.S. Department of Agriculture, Forest Service, Equipment Development Center.

APPENDIX A: PATSIM LISTING

```
110 REM PROGRAM PATSIM(INPUT,OUTPUT,TAPCONV=INPUT,TAPTERED=OUTPUT)
120 REM (*) COMMON/MIX/DST(1700),SUMD,RAT
121 DIM Dst[1700]
130 REM (*) COMMON /ADD/ NPTS,VALIN(56),ITC(8)
131 DIM Valin[56],Itc[8]
140 DIM Tim1[500],Vex[500],Qo[2500],Qdoto[2500],Qdotx[500]
150 DIM Zo[2500],Veo[2500],Vzo[2500]
160 DIM Dss[200]
170 REM (*) REAL K1,K2
180 DIM A[90]
185 DIM Itc[8]
200 DIM Ttim[100],Thim[100]
205 Ctrl$ = CHR$(12)
210 IMAGE 8(4D.5D)
220 IMAGE 8(5E)
221 IMAGE 3(5E,4X)
230 IMA 1A,20X,"S T A N D A R D   P A T T E R N   S I M U L A T I O N ",1L,30X,"R E T A R D A N T   P A T T E R N",21
240 IMAGE 5X,5D,3X,6E
250 IMAGE 20(4A)
260 IMAGE 1(1A)
270 IMAGE 10X,80A
280 IMAGE 2L,10X,"VELOCITY(KNOTS)=",8D,1L,10X,"ALTITUDE(FEET)= ",8D
281 INPUT PROMPT "What data file? ":F$
282 OPEN #1:F$,"r"
283 ON EOF(1) GOTO 2550 ! End of program
284 OPEN #7:"prn ","w"
300 A = 0 ! Initalize A
310 A[32] = 0 ! Bflag
320 A[18] = 1 ! Cflag
330 A[37] = 1 ! Alf
340 A[40] = 3.97 ! K1
350 A[41] = 12 ! K2
360 A[42] = 0.002 ! Delt
370 A[43] = 10 ! Tr
380 A[44] = 0.02 ! Tx
390 Irdqv = 0
400 A[45] = 1 ! Rflag
410 REM (*) CONTINUE
411 DELETE Tp,Lcon,Conv,Sing,Lcmax,Dela
412 DIM Dst[1700],Qo[2500],Qdoto[2500] ! ,Qdotx[500],TIM1[500],VEX[500]
413 DIM Zo[2500],Veo[2500],Vzo[2500]
420 PRINT #7 USING 230:Ctrl$
440 INPUT #1:A$ ! Read from data file
441 IF A$="" THEN 2550
450 Atst$ = SEG$(A$,1,1) | IF Atst$="*" THEN 1350 ! Is this a remark line?
460 IF A$=" " THEN 1370 ! Is this the end of a data set?
465 A1 = VAL(A$) ! A1 is the variable code
470 IF A1<0 THEN 1370
480 INPUT #1:A2 ! A2 is the value of the variable
510 PRINT #7 USING 240:A1,A2
530 J = A1 ! Renaming the variable label
540 IF J<=0 THEN 1300
550 A[J] = A2 ! Renaming the variable value
555 GOSUB 10000 ! Subroutine to change the names in the A array
```

```
556 IF J<>5 THEN 560
557 INPUT #1:M,N$,C$ ! drop#, comment, file for storage
560 IF J<>53 OR A[53]<=0 THEN 580 ! Not Add
561 FOR K = 1 TO 8 | INPUT #1:Itc[K] | NEXT K ! Which patterns are computed?
570 IMAGE 8(1D)
580 IF J<>30 THEN 620 ! Not Ttab (tabular door angle vs time)
590 IF A[J]=0 THEN 620 ! Ttab=0 deselected (Tabular door angle vs time)
600 PRINT #7 USING 601:
601 IMAGE 11,"DOOR ANGLE VS TIME DATA",7X,"TIME-SEC",6X,"ANGLE-DEG"
610 INPUT #1:Ttim[N],Thtim[N] ! Door angle vs time data
620 REM (*) CONTINUE
630 IF J<>24 THEN 1300 ! Not Rdqv (Quantity discharged vs time)
640 IF A[J]=0 THEN 1300 ! Rdqv=0 deselected (Quantity discharged vs time)
650 IF A[J]>0 THEN 780 ! Rdqv selected (Quantity discharged vs time)
660 REM INPUT Q AND THETA VS. TIME AND USE  TABLE AS IS
670 Rdqv = -Rdqv
680 Ant = Rdqv
690 Nt = Ant ! number of points read from file
700 FOR N = 1 TO Nt | INPUT #1:Tim1[N],Qdoto[N],Veo[N] | NEXT N ! Read data
710 IMA " QUANTITY AND DOOR ANGLE VS TIME DATA",11,2X,"TIME-SEC",8X,"Q-GAL",8X,"ANGLE-DEG"
720 PRINT #7 USING 710:
730 FOR N = 1 TO Nt
740   PRI #7 USI 220:Tim1[N],Qdoto[N],Veo[N] ! Quantity disc. and theta vs time
741 NEXT N
750 GOTO 1280
760 REM INPUT Q AND THETA VS. TIME, INTERPOLATE VALUES EVERY TX SECONDS,
770 REM AND EXTRAPOLATE THE TABLE TO GALI NUMBER OF CALLONS
780 Nti = Rdqv
790 FOR N = 1 TO Nti | INPUT #1:Qo[N],Zo[N],Vzo[N] | NEXT N ! Read data
800 PRINT #7 USING 710:
810 FOR N = 1 TO Nti
820   PRINT #7 USING 221:Qo[N],Zo[N],Vzo[N] ! Quantity disc. and theta vs time
821 NEXT N
830 Tim1[1] = 0 ! Beginning the extrapolation between Time,Quantity points
840 Qdoto[1] = 0
850 Veo[1] = 0
860 I = 1
870 I = I+1
880 Tim1[I] = Tim1[I-1]+Tx
890 FOR N = 1 TO Nti
900   ON SGN(Tim1[I]-Qo[N])+2 GOTO 1060,990,910
910   REM (*) CONTINUE ! Case: positive values
911 NEXT N
920 Timsav = Tim1[I]
930 Tim1[I] = Qo[Nti]
940 Qdoto[I] = Zo[Nti]
950 Veo[I] = Vzo[Nti]
960 Ant = I
970 Nt = I
980 GOTO 1090
990 Qdoto[I] = Zo[N] ! Case: zero
1000 Veo[I] = 0.5*(Vzo[N]+Vzo[N-1])
1010 IF N<>Nti THEN 870
1020 Timsav = Tim1[I]+Tx
1030 Ant = I
1040 Nt = I
```

```
1050 GOTO 1090
1059 ! Case: negative values
1060 Qdoto[I] = (Tim1[I]-Qo[N-1])/(Qo[N]-Qo[N-1])*(Zo[N]-Zo[N-1])+Zo[N-1]
1070 Veo[I] = 0.5*(Vzo[N]+Vzo[N-1])
1080 GOTO 870
1090 IF Qdoto[I]>=Gali-1.E-06 THEN 1280 ! extrapolation finished?
1100 Tfin = (Gali-Zo[Nti-1])/(Zo[Nti]-Zo[Nti-1])*(Qo[Nti]-Qo[Nti-1])+Qo[Nti-1]
1110 I = I+1
1120 Tim1[I] = Timsav
1130 GOTO 1160
1140 I = I+1
1150 Tim1[I] = Tim1[I-1]+Tx
1160 IF Tim1[I]>Tfin THEN 1230
1170 Qdoto[I] = (Gali-Zo[Nti])*((Tim1[I]-Qo[Nti])/(Tfin-Qo[Nti]))+Zo[Nti]
1180 Veo[I] = Vzo[Nti]
1190 IF Tim1[I]<Tfin THEN 1140
1200 Ant = I
1210 Nt = I
1220 GOTO 1280
1230 Tim1[I] = Tfin
1240 Qdoto[I] = Gali
1250 Veo[I] = Vzo[Nti]
1260 Ant = I
1270 Nt = I
1280 REM (*) CONTINUE ! End of extrapolating between points
1290 Irdqv = 1 ! set flag quantity dischaged data read from file
1300 REM (*) CONTINUE
1310 GOTO 440
1320 STOP
1350 PRINT #7 USING 270:A$ ! Print comment line
1360 GOTO 440
1370 REM (*) CONTINUE
1380 PRINT #7 USING 280:Vaci,Alt1 ! End of reading data set
1390 K1 = 3.97
1400 IF Rflag=2 THEN K1 = 4.4 ! flag Rflag=2 for water-like retardants
1410 Ve = 0.0
1420 FOR J = 1 TO 1700 ! initalize Dst
1430   Dst[J] = 0.0
1440   REM (*) CONTINUE
1441 NEXT J
1450 FOR I = 1 TO 100 ! initalize Dss
1460   Dss[I] = 0.0
1470   REM (*) CONTINUE
1471 NEXT I
1510 Jr = Tr
1520 Jr2 = Jr/2
1530 Vac = Vaci*1.689 ! knots to feet per second
1540 Gal = Gali*Cflag ! amount of retardant released
1550 K = 1
1560 Dt = 0.02
1580 G = 32.17 ! acceleration due to gravity
1590 G2 = 2.0*G
1600 IF Irdqv<1 THEN 1680 ! flag Irdqv=1 then data read from file
1610 Qdotx[1] = 0
1620 Vex[1] = 0
1630 FOR N = 2 TO Nt ! for constant ejection velocity=16 fps
1640   Qdotx[N] = (Qdoto[N]-Qdoto[N-1])*0.13368/(Tim1[N]-Tim1[N-1])
```

```
1650   Vex[N] = 16
1660   REM (*) CONTINUE
1661 NEXT N
1670 Irdqv = 0
1680 REM (*) CONTINUE
1690 IF A[54]<>0 THEN 410 ! flag A(54)=1 stop after flow value is determined
1700 Dt = 0.02
1710 Z = 0
1720 Delz = 4.0
1730 Jk = -Jr2+1
1740 Xout = 1
1750 Qsum = 0
1760 Zt = 0
1770 Dqout = Qdotx[1]
1780 FOR N = 2 TO Nt
1790   Jk = Jk+Jr
1800   Dt = Tim1[N]-Tim1[N-1]
1810   Qs = Qdotx[N]*Dt
1820   Qsum = Qs+Qsum
1830   IF Bflag<>1 THEN 1850 ! Bflag=1 then print bulk increment data
1840   PRINT #7 USING 220:Tim1[N],Vex[N],Qdotx[N],Qs,Qsum
1850   REM (*) CONTINUE
1860   REM (*) CONTINUE
1861 NEXT N
1870 IF Bflag<>2.0 THEN 1890
1880 GOTO 410
1890 REM (*) CONTINUE
1900 Ant = Nt
1910 Xout = 1.0
1920 Xlast = 1.0
1930 Qqq = 0.0
1940 FOR Km = 2 TO Nt
1950   Dt = Tim1[Km]-Tim1[Km-1] ! time
1960   Qsum = 0.0
1970   Ve = Vex[Km] ! ejection velocity
1980   Qdot = Qdotx[Km]
1990   Q = Qdot*Dt*Cflag ! quantity discharged
2000   IF Q<=0 THEN 2310
2010   Qqq = Qqq+Q ! cummulative quantity discharged
2020   Xout = 1
2030   Zt = 0
2040   Xx = 0
2050   Tstar = 0
2060   Tmt = Tim1[Km]
2070   Xlast = Tmt*Vac
2080   FOR Jj = 2 TO 100
2090     Zt = Zt+Delz
2100     V = SQR(Ve^2+G2*Zt)
2110     Tstar = Delz/V+Tstar
2120     Ttt = Tstar+Tmt
2130     Dqd = EXP(K1*Tstar)/(Vac*Q)*K2
2140     Xx = Delz*Vac/V+Xx
2150     Xout = Xx+Tmt*Vac
2160     Xr = Xout
2170     N11 = Xlast
2180     N12 = Xr
2190     Diff = Xr-Xlast+1
```

```
2200      Dqout = Delz/V*Dqd
2210      REM      DENS=DQD*DELZ/(V*DIFF)
2220      IF Dqout>Q-Qsum THEN Dqout = Q-Qsum
2230      Dens = Dqout/Diff
2240      FOR N2 = INT(N11) TO INT(N12) ! calculating dst
2250        Dst[N2] = Dst[N2]+Dens
2251      NEXT N2
2260      Qsum = Qsum+Dqout
2270      Xlast = Xout
2280      IF Qsum>=Q THEN EXIT TO 2300
2290      REM (*) CONTINUE
2291    NEXT Jj
2300    REM (*) CONTINUE
2310    REM (*) CONTINUE
2311 NEXT Km
2320 Jm = 0
2330 Sumd = 0
2340 FOR N3 = 1 TO 1700
2350   Sumd = Sumd+Dst[N3]
2360   REM (*) CONTINUE
2361 NEXT N3
2370 Jk = 0
2380 Rat = Gal/Sumd
2390 FOR Ij = 1 TO 1700 STEP 25
2400   Jk = Jk+1
2410   FOR Jj = 1 TO 25
2420     Jm = Ij+Jj-1
2430     Dss[Jk] = Dss[Jk]+Dst[Jm]
2440     REM (*) CONTINUE
2441   NEXT Jj
2450   Dss[Jk] = Dss[Jk]*Rat
2460   REM (*) CONTINUE
2461 NEXT Ij
2470 Sumk = 0
2480 FOR I = 1 TO 68
2490   Sumk = Dss[I]+Sumk
2500   REM (*) CONTINUE
2501 NEXT I
2510 REM CALL MIXUN(GAL,VACI,ALT1,RFLAG,FPAT,FRAN,FE)
2511 PRINT "subroutine MIXUN"
2512 GOSUB 2560
2520 IF Add<=0 THEN 410 ! don't calculate line length table
2530 REM CALL PATADD (VACI)
2531 PRINT "subroutine PATADD"
2532 GOSUB 6550
2540 GOTO 410
2550 CLOSE
2551 REM
2552 END
2560 REM SUBROUTINE MIXUN(GAL,VAC,ALT1,RFLAG,FPAT,FRAN,FE)
2570 REM (*) COMMON/MIX/DST(1700),SUMD,RAT
2580 REM (*) COMMON /ADD/ NPTS,VALIN(56),ITC(8)
2590 DIM Ud[28,56],Nd[28,56],Cd[28,56]
2600 DIM Mi[60],Mo[60],M1[60],M2[60]
2610 DIM Cmi[60],Cmo[60],Cm1[60],Cm2[60]
2620 DIM P[15]
2630 DIM Mii[60],Cmii[60]
```

```
2640 REM (*) REAL ND,LAMDA,MI,MO,M1,M2,CMII
2650 Im = 28
2660 Jm = 56
2670 Delx = 15
2680 Dely = 30
2690 Alt2 = Alt1*Alt1
2700 IF Rflag>1 THEN 2850
2710 REM      C-R PARAMETERS FOR PHOSCHEK RETARDANT
2720 IF Vaci<=130 THEN 2750
2730 Semx = 40.0+0.104048*Alt1-6.90477E-05*Alt2
2740 GOTO 2760
2750 Semx = 40.0+0.255714*Alt1-0.000185714*Alt2
2760 REM (*) CONTINUE
2770 Lamda = 0.15+5.E-05*Alt1
2780 IF Vaci<=130 THEN 2810
2790 Sigma = 8.0+0.0485715*Alt1-2.85715E-05*Alt2
2800 GOTO 2820
2810 Sigma = 8.0+0.0659048*Alt1-4.19048E-05*Alt2
2820 REM (*) CONTINUE
2830 Pctr = 85.18-0.00535*Alt1
2840 GOTO 2960
2850 REM (*) CONTINUE
2860 REM      C-R PARAMETERS FOR WATER LIKE RETARDANTS
2870 IF Alt1>482 THEN 2910
2880 Semx = 27.5583+0.222214*Alt1
2890 Sigma = 3.11609+0.0746535*Alt1
2900 GOTO 2930
2910 Semx = 135
2920 Sigma = 36.0427+0.00821018*Alt1
2930 REM (*) CONTINUE
2940 Lamda = 0.15+5.E-05*Alt1
2950 Pctr = 75.18-0.02487*Alt1
2960 REM (*) CONTINUE
2970 REM
2980 Areaf = 100/(Delx*Dely)
2990 REM      FORM MARGINAL RANGE WITH CELL SIZE = DELY
3000 FOR I = 1 TO Jm
3010   Mi[I] = 0
3011 NEXT I
3020 Jk = 0
3030 FOR Ij = 1 TO 1680 STEP 30
3040   Jk = Jk+1
3050   FOR Jj = 1 TO 30
3060     Jn = Ij+Jj-1
3070     Mi[Jk] = Mi[Jk]+Dst[Jn]
3080     REM (*) CONTINUE
3081   NEXT Jj
3090   Mi[Jk] = Mi[Jk]*Rat
3100   REM (*) CONTINUE
3101 NEXT Ij
3110 FOR I = 1 TO Jm
3120   Mii[I] = Mi[I]*(Pctr/100.0)
3121 NEXT I
3130 REM
3140 REM      FORM ELLITICAL UNIFORM GROUND DISTRIBUTION AND MARGINAL
3150 Xm = Im/2.0*Delx
```

```
3160 FOR I = 1 TO Im
3170   FOR J = 1 TO Jm
3180     Ud[I,J] = 0
3190     Nd[I,J] = 0
3200     Cd[I,J] = 0
3201   NEXT J
3202 NEXT I
3210 Jm1 = 1
3220 FOR I = 1 TO Jm
3230   IF Mi[I]>0 THEN EXIT TO 3260
3240   Jm1 = Jm1+1
3250   REM (*) CONTINUE
3251 NEXT I
3260 REM (*) CONTINUE
3270 FOR I = Jm1 TO Jm
3280   IF Mi[I]<=0 THEN EXIT TO 3310
3290   Jm2 = I
3300   REM (*) CONTINUE
3301 NEXT I
3310 REM (*) CONTINUE
3320 A2 = Semx^2
3330 B2 = ((Jm2-Jm1+1)*Dely/2.0)^2
3340 Ym = (Jm2+Jm1-1)*Dely/2.0
3350 Nc = 0
3360 X = -Delx/2
3370 FOR I = 1 TO Im
3380   X = X+Delx
3390   Y = -Dely/2
3400   FOR J = 1 TO Jm
3410     Y = Y+Dely
3420     Ee = (X-Xm)^2/A2+(Y-Ym)^2/B2
3430     IF Ee-1>0 THEN 3460
3440     Ud[I,J] = 1
3450     Nc = Nc+1
3460     REM (*) CONTINUE
3461   NEXT J
3470   REM (*) CONTINUE
3471 NEXT I
3480 Fe = 1.0/INT(Nc)
3490 Ae = Lamda*Gal*(Pctr/100.0)
3500 Ca = Fe*Ae
3510 FOR I = 1 TO Im
3520   FOR J = 1 TO Jm
3530     IF Ud[I,J]=1 THEN Ud[I,J] = Ca
3540     REM (*) CONTINUE
3541   NEXT J
3542 NEXT I
3550 FOR J = 1 TO Jm
3560   M1[J] = 0
3570   FOR I = 1 TO Im
3580     M1[J] = M1[J]+Ud[I,J]
3590     REM (*) CONTINUE
3591   NEXT I
3600   REM (*) CONTINUE
3601 NEXT J
3610 REM
3620 REM      SUBTRACT UNIFORM MARGINAL FROM MACPHERSON MARGINAL
```

```
3630 FOR J = 1 TO Jm
3640   Temp = Mii[J]-M1[J]
3650   ON SGN(Temp)+2 GOTO 3660,3680,3680
3660   M2[J] = 0
3670   GOTO 3690
3680   M2[J] = Temp
3690   REM (*) CONTINUE
3691 NEXT J
3700 REM
3710 REM      DEVELOP NORMAL DISTRIBUTION CONDITIONALS
3720 Pl = 0.5
3730 Im2 = INT(Im/2)
3740 X = 0
3750 FOR I = 1 TO Im2
3760   X = X+Delx
3770   Xos = X/Sigma
3778   GOTO 4800
3780   Pn = Cdfn
3790   IF Xos>4 THEN Pn = 1
3800   P[I] = Pn-Pl
3810   Pl = Pn
3820   REM (*) CONTINUE
3821 NEXT I
3830 FOR J = 1 TO Jm
3840   IF M2[J]<=0 THEN 3920
3850   FOR I = 1 TO Im2
3860     I1 = Im2-I+1
3870     I2 = I+Im2
3880     Temp = P[I]*M2[J]
3890     Nd[I1,J] = Temp
3900     Nd[I2,J] = Temp
3910     REM (*) CONTINUE
3911   NEXT I
3920   Mo[J] = M1[J]+M2[J]
3930   REM (*) CONTINUE
3931 NEXT J
3940 REM      COMBINE UNIFORM AND NORMAL DISTRIBUTIONS
3950 Sum1 = 0
3960 Sum2 = 0
3970 Sum3 = 0
3980 Sum4 = 0
3990 Sum9 = 0
4000 FOR J = 1 TO Jm
4010   Sum1 = Sum1+Mi[J]
4020   Sum9 = Sum9+Mii[J]
4030   Sum2 = Sum2+M1[J]
4040   Sum3 = Sum3+M2[J]
4050   Sum4 = Sum4+Mo[J]
4051 NEXT J
4060 Sum5 = 0
4070 Sum6 = 0
4080 Sum7 = 0
4090 Sum8 = 0
4100 Sum10 = 0
4110 FOR J = 1 TO Jm
4120   Sum5 = Sum5+Mi[J]
4130   Sum10 = Sum10+Mii[J]
```

```
4140   Sum6 = Sum6+M1[J]
4150   Sum7 = Sum7+M2[J]
4160   Sum8 = Sum8+Mo[J]
4170   Cmi[J] = Sum5/Sum1
4180   Cmii[J] = Sum10/Sum9
4190   Cm1[J] = Sum6/Sum2
4200   Cm2[J] = Sum7/Sum3
4210   Cmo[J] = Sum8/Sum4
4220   FOR I = 1 TO Im
4230     Ud[I,J] = Ud[I,J]*Areaf
4240     Nd[I,J] = Nd[I,J]*Areaf
4250     Cd[I,J] = Ud[I,J]+Nd[I,J]
4260     REM (*) CONTINUE
4261   NEXT I
4270   REM (*) CONTINUE
4271 NEXT J
4280 REM      OUTPUT RESULTS
4290 PRINT #7 USING 4750:Ctrl$
4300 PRINT #7 USING 4760:
4305 PRINT #7 USING "4X,S":
4310 FOR I = 1 TO Im | PRINT #7 USING "4D,S":I | NEXT I
4315 PRINT #7:
4320 FOR J = 1 TO Jm
4330   PRINT #7 USING "3D,1X,S":J
4340   FOR I = 1 TO Im | PRINT #7 USING 4780:Cd[I,J] | NEXT I
4341   PRINT #7:
4342 NEXT J
4350 IF Fpat<=1 THEN 4630
4360 REM      MULTIPLE PATTERN CODING
4370 Npat = Fpat-1
4380 Nran = Fran
4390 Ncran = Fcran
4400 FOR I = 1 TO Im
4410   FOR J = 1 TO Jm
4420     Nd[I,J] = Cd[I,J]
4421   NEXT J
4422 NEXT I
4430 Nc = 0
4440 Nr = 0
4450 FOR N = 1 TO Npat
4460   Nc = Nc+Ncran
4470   Nr = Nr+Nran
4480   FOR I = 1 TO Im
4490     I1 = INT(I)-INT(Nc)
4510     FOR J = 1 TO Jm
4520       J1 = J-Nr
4530       IF J1<1 OR J1>Jm THEN 4550
4540       Cd[I,J] = Cd[I,J]+Nd[I1,J1]
4550       REM (*) CONTINUE
4551     NEXT J
4560     REM (*) CONTINUE
4561   NEXT I
4570   REM (*) CONTINUE
4571 NEXT N
4580 PRINT #7 USING 4750:
4590 PRINT #7 USING 4640:
4600 FOR I = 1 TO Im | PRINT #7 USING 4770:I | NEXT I
```

```
4610 FOR J = 1 TO Jm
4620   FOR I = 1 TO Im | PRINT #7 USING 4780:J,Cd[I,J] | NEXT I
4621 NEXT J
4630 REM (*) CONTINUE
4640 IMAGE 47X,"MULTIPLE PATTERN DATA"
4650 REM CALL UNCOM(CD,GAL)
4651 PRINT "subroutine UNCOM"
4652 GOSUB 5250
4655 IF A[5]>0 THEN GOSUB 20000
4660 REM CALL PPRINT(CD)
4661 PRINT "subroutine PPRINT"
4662 GOSUB 5990
4670 Npts = 0
4680 FOR J = 1 TO Jm
4690   IF Cd[14,J]=0 THEN 4730
4700   Npts = Npts+1
4710   Valin[J] = Cd[14,J]
4720   REM (*) CONTINUE
4721 NEXT J
4730 REM (*) CONTINUE
4740 RETURN
4750 IMAGE 1A
4760 IMAGE 47X,"DETAILED PATTERN DATA"
4780 IMAGE 2D.1D,S
4790 END
4800 REM FUNCTION CDFN(X)
4810 DIM Af[6],Df[6],Cf[6,10]
4820 DIM Ef[60]
4830 REM (*) EQUIVALENCE (E(1),C(1,1))
4835 RESTORE 4840
4840 DATA 0.625,1.25,2.0,2.45,3.5,4.62
4841 FOR J = 1 TO 6 | READ Af[J] | NEXT J
4850 DATA 0.3,0.925,1.625,2.225,2.95,4.15
4851 FOR J = 1 TO 6 | READ Df[J] | NEXT J
4860 DATA 0.00067982403291,-0.0012709753598,0.000679645257
4865 DATA -8.8500314297E-05,1.4791554152E-07,5.4879072878E-07
4870 DATA 0.0051028640888,-0.0014822649744,-3.4589883732E-07
4880 DATA 0.00056826070991,-6.1965013125E-05,-8.6656125337E-07
4890 DATA -0.0060160862379,0.0087718965604,-0.0030883401043
4900 DATA -0.00045015531032,0.00022266710841,6.6877769441E-07
4910 DATA -0.022725611373,-0.0020200415601,0.0072141082947
4920 DATA -0.0013872389725,-0.00044390018986,-6.4084653798E-07
4930 DATA 0.033555772127,-0.034681674488,-0.001067703944
4940 DATA 0.0055422185916,0.00062978750848,6.2471782478E-07
4950 DATA 0.072703311825,0.047642403207,-0.024859750804
4960 DATA -0.010221129286,-0.00066382630882,-4.2105004094E-07
4970 DATA -0.14093895854,0.056850293056,0.057420315819
4980 DATA 0.011850195831,0.00051265678121,2.0742133302E-07
4990 DATA -0.1546891297,-0.22180615138,-0.06538370517
5000 DATA -0.0088864030978,-0.00027657162532,-0.076856040218
5010 DATA 0.5156304546,0.23979043073,0.040236129479
5020 DATA 0.0039938885701,9.3751413487E-05,1.8722020822E-08
5030 DATA 0.16431337971,0.40458836515,0.48922186659
5040 DATA 0.49917416726,0.49998489849,0.49999999779
5041 FOR J = 1 TO 60 | READ Ef[J] | NEXT J
5042 FOR J = 1 TO 10
5043   FOR K = 1 TO 6
```

```
5044     Cf[K,J] = Ef[(J-1)*6+K]
5045   NEXT K
5046 NEXT J
5050 Y = Xos*0.70710678119
5060 Sgny = 1
5070 ON SGN(Y)+2 GOTO 5100,5080,5120
5080 Cdfn = 0.5
5090 GOTO 3780
5100 Sgny = -1
5110 Y = -Y
5120 FOR K = 1 TO 6
5130   IF Y-Af[K]<=0 THEN EXIT TO 5170
5140   REM (*) CONTINUE
5141 NEXT K
5150 Z = 0.5
5160 GOTO 5220
5170 Y = Y-Df[K]
5180 Z = Cf[K,1]
5190 FOR J = 2 TO 10
5200   Z = Z*Y+Cf[K,J]
5210 NEXT J
5220 Cdfn = 0.5+Sgny*Z
5230 GOTO 3780
5240 END
5250 REM SUBROUTINE UNCOM(CD,GALLON)
5260 REM
5270 REM         COMPUTES CONTOURS FOR SIMULATED PATTERNS
5280 REM
5290 DIM Cd[28,56],Btot[12],Itot[12]
5300 DIM Cmean[12]
5310 REM (*) REAL ITOT
5320 DATA 0.1,0.6,1.5,2.5,3.5,4.5,5.5,6.5,7.5,8.5,9.5,10.5
5330 RESTORE 5320
5340 FOR I = 1 TO 12 | READ Cmean[I] | NEXT I
5350 Im = 28
5360 Jm = 56
5370 Sum0 = 0
5380 Sum1 = 0
5390 FOR I = 1 TO 12
5400   Btot[I] = 0
5410   Itot[I] = 0
5411 NEXT I
5420 FOR I = 1 TO Im
5430   FOR J = 1 TO Jm
5440     Tot = Cd[I,J]
5450     IF Tot=0 THEN 5690
5460     IF Tot>0 AND Tot<=0.2 THEN 5480
5470     GOTO 5520
5480     Btot[1] = Btot[1]+Tot
5490     Itot[1] = Itot[1]+1
5500     Sum0 = Sum0+Tot*4.5
5510     GOTO 5690
5520     IF Tot>0.2 AND Tot<=1 THEN 5540
5530     GOTO 5580
5540     Btot[2] = Btot[2]+Tot
5550     Itot[2] = Itot[2]+1
5560     Sum0 = Sum0+Tot*4.5
```

```
5570     GOTO 5690
5580     FOR K = 1 TO 9
5590       IF Tot>K AND Tot<=K+1 THEN 5610
5600       GOTO 5650
5610       Btot[K+2] = Btot[K+2]+Tot
5620       Itot[K+2] = Itot[K+2]+1
5630       Sum0 = Sum0+Tot*4.5
5640       EXIT TO 5690
5650       REM (*) CONTINUE
5651     NEXT K
5660     Btot[12] = Btot[12]+Tot
5670     Itot[12] = Itot[12]+1
5680     Sum0 = Sum0+Tot*4.5
5690     REM (*) CONTINUE
5691   NEXT J
5692 NEXT I
5700 FOR I = 1 TO 12
5710   Btot[I] = Btot[I]*4.5
5711 NEXT I
5720 Perr = Sum0/Gal*100
5730 FOR I = 1 TO 12
5740   Itot[I] = Itot[I]*450
5750   Sum1 = Sum1+Itot[I]
5751 NEXT I
5760 PRINT #7 USING 5900:
5765 PRINT #7 USING 5910:
5770 FOR K = 1 TO 11 | PRINT #7 USING "5D.4D,3X,S":Btot[K] | NEXT K
5775 PRINT #7 USING "1L,4X,3A,1L,5D.4D":">10",Btot[12]
5780 PRINT #7 USING 5940:Sum0,Perr
5790 Sum2 = 0
5800 Sum3 = 0
5810 FOR I = 1 TO 12
5820   Sum2 = Sum2+Btot[I]*Cmean[I]
5830   Sum3 = Sum3+Btot[I]
5840   REM (*) CONTINUE
5841 NEXT I
5850 Sum2 = Sum2/Sum3
5860 PRINT #7 USING 5960:Sum2
5870 PRINT #7 USING 5920:
5879 PRINT #7 USING 5930:
5880 FOR K = 1 TO 11 | PRINT #7 USING "9D,3X,S":Itot[K] | NEXT K
5881 PRINT #7 USING "1L,4X,3A,1L,9D":">10",Itot[12]
5890 PRINT #7 USING 5950:Sum1
5900 IMA 21,11X,"CONTOUR INTERVALS FOR RETARDANT DISTRIBUTION (GALLONS/100 SQUARE FEET) TOTAL WITHIN EACH INTERVAL"
5910 IMA 2X,"0.0-0.2      0.3-1.0      1.1-2.0  .  2.1-3.0      3.1-4.0      4.1-5.0      5.1-6.0      6.1-7.0      7.1-8.0      8.1-
5920 IMA 11,12X,"CONTOUR INTERVALS FOR RETARDANT DISTRIBUTION (SQUARE-FOOT COVERAGE ) - TOTAL WITHIN EACH INTERVAL"
5930 IMA 2X,"0.0-0.2      0.3-1.0      1.1-2.0  .  2.1-3.0      3.1-4.0      4.1-5.0      5.1-6.0      6.1-7.0      7.1-8.0      8.1-
5940 IMA 2X,"TOTAL AMOUNT OF RETARDANT ON GRID = ",7D.2D," GALLONS",10X,"PERCENT OF TOTAL = ",5D.3D
5950 IMAGE 10X,"TOTAL AREA COVERED ",11D," SQUARE FEET."
5960 IMAGE 2X,"AVERAGE PATTERN LEVEL IS ",4D.D," GALLONS PER 100 SQUARE FEET"
5970 RETURN
5980 END
5990 REM (*) SUBROUTINE PPRINT(AA)
6000 DIM T[12],D[12]
6001 DIM S$[13](132),P$[28](132)
6010 DATA 10,9,8,7,6,5,4,3,2,1,0.3,0
6020 RESTORE 6010
6030 FOR I = 1 TO 12 | READ T[I] | NEXT I
6040 DATA "  10","   9","   8","   7","   6","   5","   4","   3","   2"
6050 DATA "   1","   +","   .","    "
```

```
6060 RESTORE 6040
6070 FOR I = 1 TO 13 | READ S$[I] | NEXT I
6080 Im = 28
6090 Jm = 56
6100 Y = -15
6110 Dy = 30
6120 PRINT #7 USING 6470:Ctrl$
6121 PRINT #7 USING 6480:
6122 PRINT #7 USING 6481:
6123 PRINT #7 USING 6482:
6124 PRINT #7 USING 6483:
6125 PRINT #7 USING 6484:
6126 PRINT #7 USING 6485:
6127 PRINT #7 USING 6486:
6128 PRINT #7 USING 6487:
6129 PRINT #7 USING 6488:
6130 PRINT #7 USING 6489:
6131 PRINT #7 USING 6490:
6132 PRINT #7 USING 6491:
6133 PRINT #7 USING 6492:
6134 PRINT #7 USING 6493:
6139 PRINT #7 USING "4X,S":
6140 FOR I = 1 TO Im | PRINT #7 USING "4D,S":I | NEXT I
6141 PRINT #7 USING "3L":
6150 Jst = 0
6160 FOR J = 1 TO Jm
6170   FOR I = 1 TO Im
6180     P$[I] = S$[13]
6181   NEXT I
6190   Ist = 0
6200   FOR I = 1 TO Im
6210     FOR K = 1 TO 12
6220       IF Cd[I,J]>T[K] THEN EXIT TO 6250
6230       REM (*) CONTINUE
6231     NEXT K
6240     GOTO 6280
6250     P$[I] = S$[K]
6260     Ist = 1
6270     Jst = 1
6280     REM (*) CONTINUE
6281   NEXT I
6290   IF Jst=1 AND Ist=0 THEN EXIT TO 6330
6300   Y = Y+Dy
6310   PRI #7 USI 6510:J | FOR I1 = 1 TO Im | PRI #7 USI 6511:P$[I1] | NEX I1
6311   PRINT #7 USING 6512:Y
6320   REM (*) CONTINUE
6321 NEXT J
6330 REM (*) CONTINUE
6340 FOR I = 1 TO 12
6350   D[I] = 0
6351 NEXT I
6360 I = 14
6370 FOR J = 1 TO Jm
6380   FOR K = 1 TO 12
6390     IF Cd[I,J]>T[K] THEN D[K] = D[K]+Dy
6400     REM (*) CONTINUE
6401   NEXT K
```

```
6410   REM (*) CONTINUE
6411 NEXT J
6420 PRINT #7 USING 6520:
6430 FOR I = 1 TO 12
6440   K = 12-I+1
6450   PRINT #7 USING 6530:D[K],T[K]
6451 NEXT I
6460 RETURN
6470 IMAGE 1A
6480 IMAGE 40X,"S C A L E D   P A T T E R N   P L O T ",1L
6481 IMAGE 38X,"CELL SIZE IS 15 FEET WIDE BY 30 FEET LONG",1L
6482 IMAGE 38X," . --- 0.0 TO 0.2 GALLONS/100 SQUARE FEET"
6483 IMAGE 38X," + --- 0.3 TO 1.0 GALLONS/100 SQUARE FEET"
6484 IMAGE 38X," 1 --- 1.1 TO 2.0 GALLONS/100 SQUARE FEET"
6485 IMAGE 38X," 2 --- 2.1 TO 3.0 GALLONS/100 SQUARE FEET"
6486 IMAGE 38X," 3 --- 3.1 TO 4.0 GALLONS/100 SQUARE FEET"
6487 IMAGE 38X," 4 --- 4.1 TO 5.0 GALLONS/100 SQUARE FEET"
6488 IMAGE 38X," 5 --- 5.1 TO 6.0 GALLONS/100 SQUARE FEET"
6489 IMAGE 38X," 6 --- 6.1 TO 7.0 GALLONS/100 SQUARE FEET"
6490 IMAGE 38X," 7 --- 7.1 TO 8.0 GALLONS/100 SQUARE FEET"
6491 IMAGE 38X," 8 --- 8.1 TO 9.0 GALLONS/100 SQUARE FEET"
6492 IMAGE 38X," 9 --- 9.1 TO 10. GALLONS/100 SQUARE FEET"
6493 IMAGE 38X," 10 --- GREATER THAN 10 GALLONS/100 SQUARE FEET"
6510 IMAGE 3D,1X,S
6511 IMAGE 4A,S
6512 IMAGE 5D," FEET",4L
6520 IMAGE 48X,"PATTERN LENGTH DATA  ",1L
6530 IMAGE 35X,5D, "FEET ABOVE ",4D.D," GALLONS/100 SQUARE FEET"
6540 END
6550 REM (*) SUBROUTINE PATADD(VACI)
6551 DELETE Dst,Qo,Qdoto,Zo,Veo,Vzo ! QDOTX,TIM1,VEX
6560 DIM Tp[2000],Lcon[9],Conv[9] ! TP[13440]
6570 DIM Sing[1680]
6580 DIM Lcmax[9],Dela[9]
6590 REM (*) COMMON /ADD/NPTS,VALIN(56),ITC(8)
6600 DATA 0.5,1,2,3,4,6,8,10,12
6610 RESTORE 6600
6620 FOR I = 1 TO 9 | READ Conv[I] | NEXT I
6630 IMA 1A,36X,"MAXIMUM LINE LENGTHS WITH CORRESPONDING TANK OPENING DELAYS ",2L
6640 IMA 1L,21X,"      NO. OF ",8(2X,"---------"),1L,21X,"      TANKS  ",8("   FEET SEC")
6660 IMAGE 2X
6670 Knots = Vaci
6680 Valin[Npts+1] = 0
6690 Valin[Npts+2] = 0
6700 Jfrst - 0
6710 REM WRITE HEADINGS
6720 PRINT #7 USING 6630:Ctrl$
6729 PRINT #7 USING "34X,S":
6730 FOR I = 1 TO 8 | PRINT #7 USING "2X,3D.D,4A,S":Conv[I]," GPC" | NEXT I
6731 PRINT #7 USING 6640:
6740 Lalt = 0
6750 REM LENGTH OF SUBCELL
6760 Mcell = 5
6770 REM NUMBER OF SUBCELLS TO START
6780 Mstcl = 3
6790 REM NUMBER OF SUBCELLS TO A CELL
6800 Mlncl = 6
```

```
6810 Fps = Knots*1.68781
6820 REM DELT IS LENGTH  (SEC) OF INTERVAL
6830 Delt = 0.1
6840 Fpdel = Fps*Delt
6850 REM COMPUTE NUMBER OF CELLS PER INTERVAL
6860 Idcell = INT(Fpdel/Mcell+0.5)
6870 REM EXPAND SINGLE PATTERN
6880 Qnext = 0
6890 Lastd = 0
6900 Nextd = Mstcl
6910 Nto = Npts+2
6920 FOR I = 1 TO Nto
6930   Qlast = Qnext
6940   Qnext = Valin[I]
6950   Slope = (Qnext-Qlast)/(Nextd-Lastd)
6960   Jx = Lastd+1
6970   FOR Ix = Jx TO Nextd
6980     Sing[Ix] = Qlast+(Ix-Lastd)*Slope
6981   NEXT Ix
6990   Lastd = Nextd
7000   Nextd = Nextd+Mlncl
7001 NEXT I
7010 Lsp = INT(Npts*Mlncl+Mlncl/2)
7020 REM MAXIMUM NUMBER OF INTERVALS
7030 Nintv = INT(Lsp/Idcell+1)
7040 REM SINGLE PATTERN IS EXPANDED
7050 REM
7060 REM ROUTINE TO ADD TOGETHER PATTERNS
7070 Ntank = 0
7080 FOR Jj = 1 TO 8
7090   Ntank = Ntank+1
7100   FOR Kc = 1 TO 9
7110     Dela[Kc] = 0
7120     Lcmax[Kc] = 0
7121   NEXT Kc
7130   IF Itc[Jj]<>1 THEN 7410
7140   FOR Jr = 1 TO Nintv
7150     J = Jr-1
7160     Idisp = INT(J*Idcell)
7170     Dly = J*Delt
7180     Maxl = INT(Lsp+(Ntank-1)*Idisp)
7190     FOR K = 1 TO Maxl
7200       Tp[K] = 0
7201     NEXT K
7210     Idat = 0
7220     FOR K = 1 TO Ntank
7230       FOR Kl = 1 TO Lsp
7240         Kk = INT(Kl+Idat)
7250         Tp[Kk] = Tp[Kk]+Sing[Kl]
7251       NEXT Kl
7260       Idat = INT(Idat+Idisp)
7261     NEXT K
7270     REM ROUTINE TO COMPUTE LENGTHS
7280     FOR I = 1 TO 9
7290       Lcon[I] = 0
7291     NEXT I
7300     FOR I = 1 TO Maxl
```

```
 7310       FOR J = 1 TO 9
 7320         IF Tp[I]>=Conv[J] THEN Lcon[J] = INT(Lcon[J]+Mcell)
 7321       NEXT J
 7330       REM (*) CONTINUE
 7331     NEXT I
 7340     FOR K = 1 TO 9
 7350       IF Lcmax[K]>=Lcon[K] THEN 7380
 7360       Lcmax[K] = INT(Lcon[K])
 7370       Dela[K] = Dly
 7380       REM (*) CONTINUE
 7381     NEXT K
 7390     REM (*) CONTINUE
 7391   NEXT Jr
 7400   PRINT #7 USING "22X,7X,1D,4X,S":Ntank
 7401   FOR I = 1 TO 8 | PRI #7 USI "2X,4D,1X,2D.D,S":Lcmax[I],Dela[I] | NEX I
 7402   PRINT #7:
 7410   REM (*) CONTINUE
 7411 NEXT Jj
 7420 REM END OF THIS ALTITUDE AND VELOCITY
 7430 RETURN
 7440 END
10000 Gali = A[17]
10010 Cflag = A[18]
10020 Rdqv = A[24]
10030 Convex = A[25]
10040 Bflag = A[32]
10050 Alf = A[37]
10060 K1 = A[40]
10070 K2 = A[41]
10080 Delt = A[42]
10090 Tr = A[43]
10100 Tx = A[44]
10110 Rflag = A[45]
10120 Fpat = A[46]
10130 Fran = A[47]
10140 Fcran = A[48]
10150 Vaci = A[51]
10160 Alt1 = A[52]
10170 Add = A[53]
10180 R = A[62]
10190 RETURN
20000 OPEN #5:C$,"f"
20010 WRITE #5:M,N$,K1,Vaci,Alt1,K2,Delz,Sigma,Cd,Gali
20020 CLOSE
```

APPENDIX B: SAMPLE PATSIM INPUT-OUTPUT

B-1 Sample input file

```
                              PATSIM INPUT

17
500
18
1
51
125
52
200
45
1
53
1
1
1
0
1
0
0
0
0
24
10
0         0        0
0.1       2.68     0
0.2   7.98     0
0.3       13.22    0
0.4       23.52    0
0.5       36       0
0.6       52.22    0
0.7       68.92    0
0.8       84.68    0
0.9       100.24   0
* DEMPSAY DC-4 4" OPEN 200' 125 KT GUM
```

B-2 Sample output

```
              S T A N D A R D   P A T T E R N   S I M U L A T I O N
                                                                          R E T A R D A N T   P A T T E R

       17   5.000000E+02
       18   1.000000E+00
       51   1.250000E+02
       52   2.000000E+02
       45   1.000000E+00
       53   1.000000E+00
       24   1.000000E+01
 QUANTITY AND DOOR ANGLE VS TIME DATA
                                  TIME-SEC        Q-GAL        ANGLE-DEG
0.00000E+00    0.00000E+00    0.00000E+00
1.00000E-01    2.68000E+00    0.00000E+00
2.00000E-01    7.98000E+00    0.00000E+00
3.00000E-01    1.32200E+01    0.00000E+00
4.00000E-01    2.35200E+01    0.00000E+00
5.00000E-01    3.60000E+01    0.00000E+00
6.00000E-01    5.22200E+01    0.00000E+00
7.00000E-01    6.89200E+01    0.00000E+00
8.00000E-01    8.46800E+01    0.00000E+00
9.00000E-01    1.00240E+02    0.00000E+00
        * DEMPSAY DC-4 4" OPEN 200' 125 KT GUM


        VELOCITY(KNOTS)=      125
                                        ALTITUDE(FEET)=       200
```

DETAILED PATTERN DATA

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.3	0.3	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.3	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.2	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.4	0.4	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.3	0.5	0.5	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.4	0.6	0.6	0.4	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.5	0.9	0.9	0.5	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.3	0.7	1.1	1.1	0.7	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.3	0.7	1.1	1.1	0.7	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.6	1.0	1.0	0.6	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.6	1.0	1.0	0.6	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.6	1.0	1.0	0.6	0.2	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.6	1.0	1.0	0.6	0.2	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.6	1.0	1.0	0.6	0.2	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.6	1.0	1.0	0.6	0.2	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.6	1.0	1.0	0.6	0.2	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.6	1.0	1.0	0.6	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.6	1.0	1.0	0.6	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.6	1.0	1.0	0.6	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.6	1.0	1.0	0.6	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.6	1.0	1.0	0.6	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.6	1.0	1.0	0.6	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.6	1.1	1.1	0.6	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.6	1.1	1.1	0.6	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.6	1.0	1.0	0.6	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.5	0.8	0.8	0.5	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.5	0.5	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
32	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
33	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
34	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
35	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
36	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
38	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
39	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
41	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
42	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
43	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
44	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
45	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
46	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
47	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
48	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
49	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
51	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
52	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
53	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
54	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
55	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
56	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

CONTOUR INTERVALS FOR RETARDANT DISTRIBUTION (GALLONS/100 SQUARE FEET) TOTAL WITHIN EACH INTERVAL

0.0-0.2	0.3-1.0	1.1-2.0	2.1-3.0	3.1-4.0	4.1-5.0	5.1-6.0	6.1-7.0	7.1-8.0	8.1-9.0	9.1-10
47.7202	212.1845	160.6453	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	[illegible]

TOTAL AMOUNT OF RETARDANT ON GRID = 420.55 GALLONS
AVERAGE PATTERN LEVEL IS 0.9 GALLONS PER 100 SQUARE FEET

CONTOUR INTERVALS FOR RETARDANT DISTRIBUTION (SQUARE-FOOT COVERAGE) - TOTAL WITHIN EACH INTERVAL

0.0-0.2	0.3-1.0	1.1-2.0	2.1-3.0	3.1-4.0	4.1-5.0	5.1-6.0	6.1-7.0	7.1-8.0	8.1-9.0	9.1-10.0
93600	47700	15300	0	0	0	0	0	0	0	0

TOTAL AREA COVERED 156600 SQUARE FEET.

S C A L E D   P A T T E R N   P L O T

CELL SIZE IS 15 FEET WIDE BY 30 FEET LONG

```
 . --- 0.0 TO 0.2 GALLONS/100 SQUARE FEET
 + --- 0.3 TO 1.0 GALLONS/100 SQUARE FEET
 1 --- 1.1 TO 2.0 GALLONS/100 SQUARE FEET
 2 --- 2.1 TO 3.0 GALLONS/100 SQUARE FEET
 3 --- 3.1 TO 4.0 GALLONS/100 SQUARE FEET
 4 --- 4.1 TO 5.0 GALLONS/100 SQUARE FEET
 5 --- 5.1 TO 6.0 GALLONS/100 SQUARE FEET
 6 --- 6.1 TO 7.0 GALLONS/100 SQUARE FEET
 7 --- 7.1 TO 8.0 GALLONS/100 SQUARE FEET
 8 --- 8.1 TO 9.0 GALLONS/100 SQUARE FEET
 9 --- 9.1 TO 10. GALLONS/100 SQUARE FEET
10 --- GREATER THAN 10 GALLONS/100 SQUARE FEET
```

```
     1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28

1                            .  .  .  .  .  .  .  .  .  .  .  .                            15 FEET

2                            .  .  .  .  .  +  +  .  .  .  .  .                            45 FEET

3                            .  .  .  .  .  .  .  .  .  .  .  .                            75 FEET

4                            .  .  .  .  .  .  .  .  .  .  .  .                           105 FEET

5                            .  .  .  .  .  +  +  .  .  .  .  .                           135 FEET

6                            .  .  .  .  +  +  +  +  .  .  .  .                           165 FEET

7                            .  .  .  .  +  +  +  +  .  .  .  .                           195 FEET
```

8	. . . . + + + + ...	225 FEET
9	. . . . + 1 1 + ...	255 FEET
10	. . . . + 1 1 + ...	285 FEET
11	. . . . + 1 1 + ...	315 FEET
12	. . . . + 1 1 + ...	345 FEET
13	. . . . + 1 1 + ...	375 FEET
14	. . . . + 1 1 + ...	405 FEET
15	. . . . + 1 1 + ...	435 FEET
16	. . . . + 1 1 + ...	465 FEET
17	. . . . + 1 1 + ...	495 FEET
18	. . . . + 1 1 + ...	525 FEET
19	. . . . + 1 1 + ...	555 FEET
20	. . . . + 1 1 + ...	585 FEET
21	. . . . + 1 1 + ...	615 FEET

22	. . . . . + 1 1 + ...	645 FEET
23	. . . . . + 1 1 + ...	675 FEET
24	. . . . . + 1 1 + ...	705 FEET
25	. . . . . + 1 1 + ...	735 FEET
26	. . . . . + + + + ...	765 FEET
27	. . . . . + + + + ...	795 FEET
28	. . . . . + + + + ...	825 FEET
29	. . . .	855 FEET

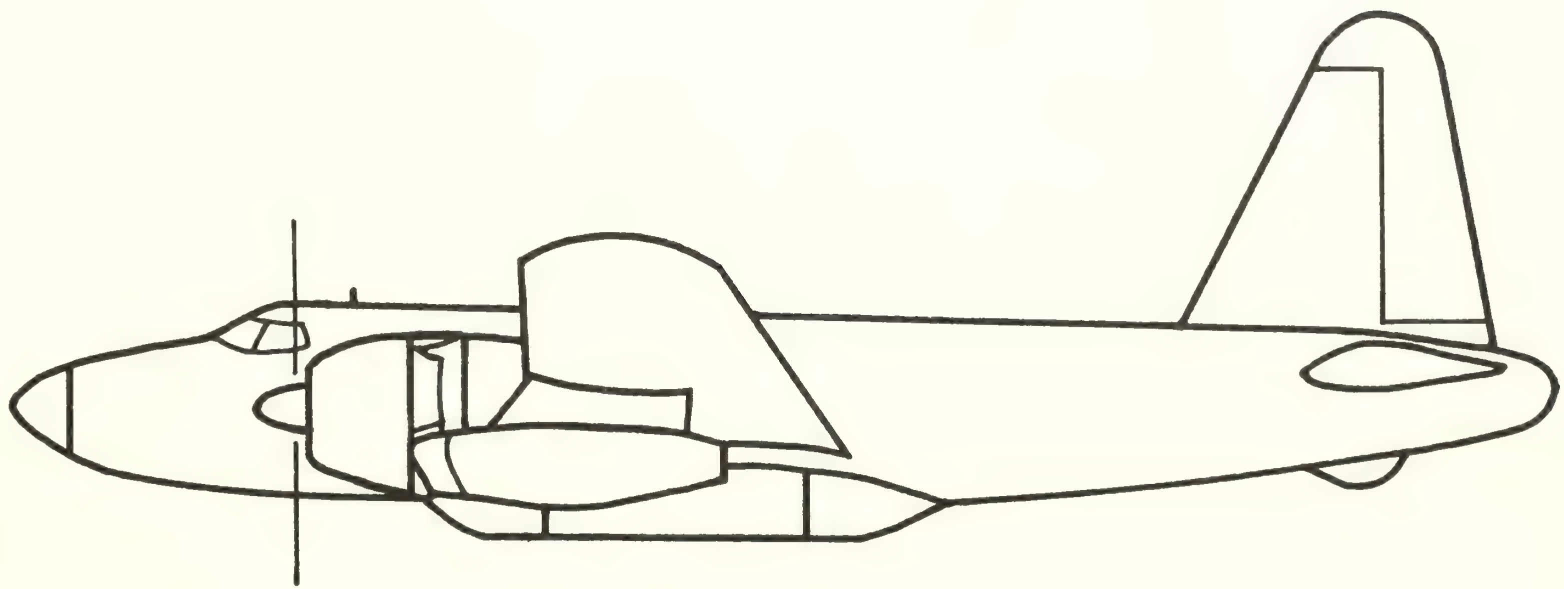
PATTERN LENGTH DATA

870FEET ABOVE	0.0	GALLONS/100 SQUARE FEET
750FEET ABOVE	0.3	GALLONS/100 SQUARE FEET
510FEET ABOVE	1.0	GALLONS/100 SQUARE FEET
0FEET ABOVE	2.0	GALLONS/100 SQUARE FEET
0FEET ABOVE	3.0	GALLONS/100 SQUARE FEET
0FEET ABOVE	4.0	GALLONS/100 SQUARE FEET
0FEET ABOVE	5.0	GALLONS/100 SQUARE FEET
0FEET ABOVE	6.0	GALLONS/100 SQUARE FEET
0FEET ABOVE	7.0	GALLONS/100 SQUARE FEET
0FEET ABOVE	8.0	GALLONS/100 SQUARE FEET
0FEET ABOVE	9.0	GALLONS/100 SQUARE FEET
0FEET ABOVE	10.0	GALLONS/100 SQUARE FEET

MAXIMUM LINE LENGTHS WITH CORRESPONDING TANK OPENING DELAYS

	0.5 GPC		1.0 GPC		2.0 GPC		3.0 GPC		4.0 GPC		6.0 GPC		8.0 GPC		10.0 GPC	
1	670	0.0	525	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
2	1390	3.6	1145	3.1	525	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
4	2830	3.6	2385	3.1	845	1.6	590	0.0	525	0.0	0	0.0	0	0.0	0	0.0

AIRTANKER PERFORMANCE GUIDE
for
BLACK HILLS/ROSENBALM
TANKED P2V-5 AIRCRAFT
(Tanker 07 — 2450 - Gallon Load)



Performance Guide PG-20

Compiled by: C. W. George, A. D. Blakely, and G. M. Johnson

MARCH 1982

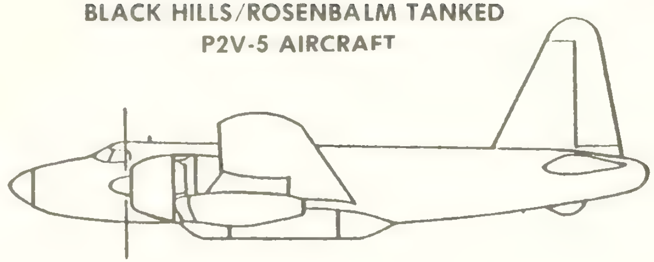
Intermountain Forest and Range Experiment Station
Forest Service, U.S. Department of Agriculture
Ogden, Utah

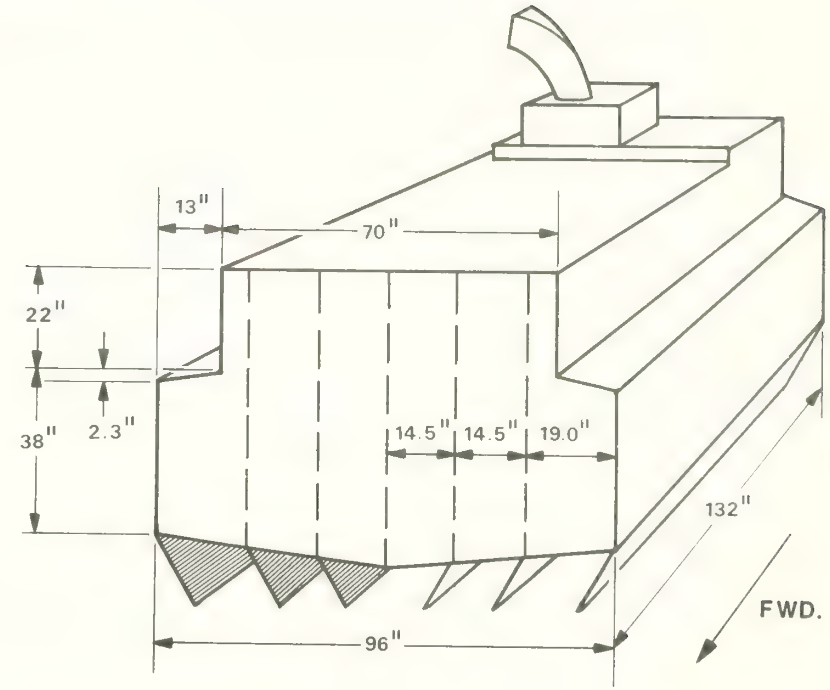
This manual is published as a part of a program to improve fire control technology, specifically through the use of fire retardant chemicals and delivery systems whose chemical and/or design characteristics are tailored to fuel and fire situation needs. This program is being conducted at the Northern Forest Fire Laboratory. Information or questions regarding these studies should be directed to the:

Northern Forest Fire Laboratory
Drawer G
Missoula, Montana 59806

*__Phos-Chek__ is a registered trademark of the Monsanto Co.
Fire-Trol is a registered trademark of the Chemonics Industries
Gelgard is a registered trademark of the Dow Chemical Co.

BLACK HILLS/ROSENBALM TANKED P2V-5 AIRCRAFT





The P2V-5 with the Rosenbalm designed tank carries 2450 gallons of retardant in two 442 and four 392 gallon compartments. As a result of differences in the door sizes, (outer door: 12.25 ft.^{2}, inner door: 8.75 ft.^{2}) the flow rate difference between separate compartments cause ground response patterns that preclude averaging. Therefore, throughout this guide "O" will be used to identify the outboard 442-gallon compartment and "I" the inboard 392-gallon compartments. A "+" used as "O+I" indicates compartment dropped simultaneously similarly "," as "O,I" indicates compartments released in sequence (trail drop).

The system is capable of releasing one, two, three, or size compartments simultaneously or in trail with the time interval controlled by an intervalometer or manually. The longest lengths of line at coverage levels up to 4 GPC are achieved using single sequence releases (trail drops). For higher coverage levels double or triple successive releases are applicable. The full salvo should be reserved for only the most difficult conditions (high wind, intense fire, high drop height).

The retardant mass has considerable momentum and has the capability to penetrate the fire plume in quantities adequate for direct suppression. The momentum also may uproot trees, damage ground equipment, or injure personnel. For this reason it is recommended that 3 or 6 compartment salvos not be used near ground operations.

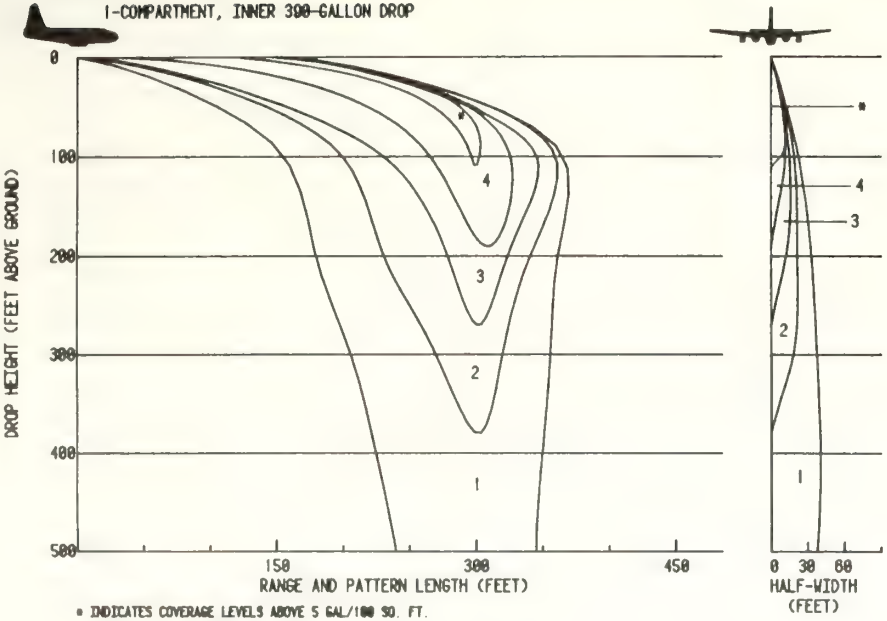
CHARACTERISTICS

Capacity	2450 Gallons		
Increment	Two 442 and Four 392 Gallon Compartments		
Compartments Released[1]	Evacuation Time (sec)	Av. Flow Rate (gallons/sec)	Peak Flow Rate (gallons/sec)
1 (I)[2]	0 70	560	700
1 (O)	0 50	880	1250
2 (I+I)	0.70	1120	1400
2 (O+I)	0 70	1180	1900
3	0 70	1750	2550
6	0 70	3500	5100

(1) Number of compartments released simultaneously
(2) (I)=Single inner compartment release
(O)=Single outer compartment release.
(I+I)=Double inner-inner compartment release.
(O+I)=Double outer-inner compartment release.
3 compartment release consists of 2 inner and 1 outer compartment

Pattern Coverage Characteristics - WATER-LIKE Retardants
Fire-Trol 100, Fire-Trol 931 (LC) and Water

1-COMPARTMENT, INNER 300-GALLON DROP

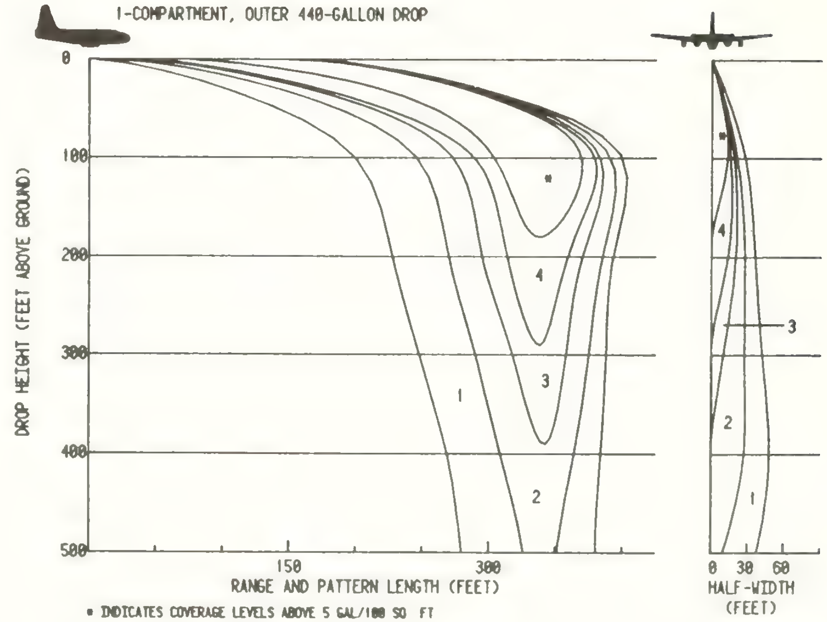


* INDICATES COVERAGE LEVELS ABOVE 5 GAL/100 SQ. FT.

Recommended For:		
Coverage Level	Fuel Model[1] (1978 NFDRS)	Description
1	A, L, S	Annual and Perennial Western grasses; tundra
2	C, H, P, U E, R,	Tall grasses; Conifer (with grasses/forbs/needles and/or woody shrubs understory) Hardwoods (winter and summer)
3	K, F[2], N, T	Light slash (conifer or hardwood); Intermediate brush (green); Sawgrass; Western woody shrubs
4	G	Shortneedle conifer (heavy dead litter)
6	D, Q, F[2]	Southern Rough; Alaska Black Spruce, Intermediate brush (cured)
Greater than 6	B, I, J, O	California mixed chaparral; Medium and heavy slash; High Pocosin

For creeping or smouldering fires reduction of one coverage level may be considered
[1] Fuel models considered to be in flammable condition
[2] Coverage level requirements for intermediate brush depend on its stage of curing.

1-COMPARTMENT, OUTER 440-GALLON DROP

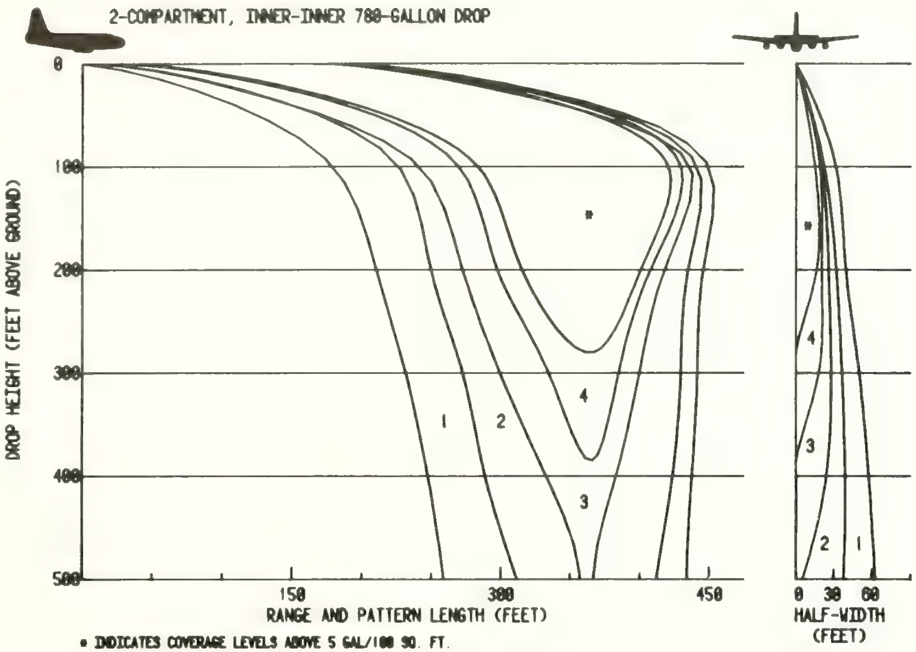


* INDICATES COVERAGE LEVELS ABOVE 5 GAL/100 SQ. FT

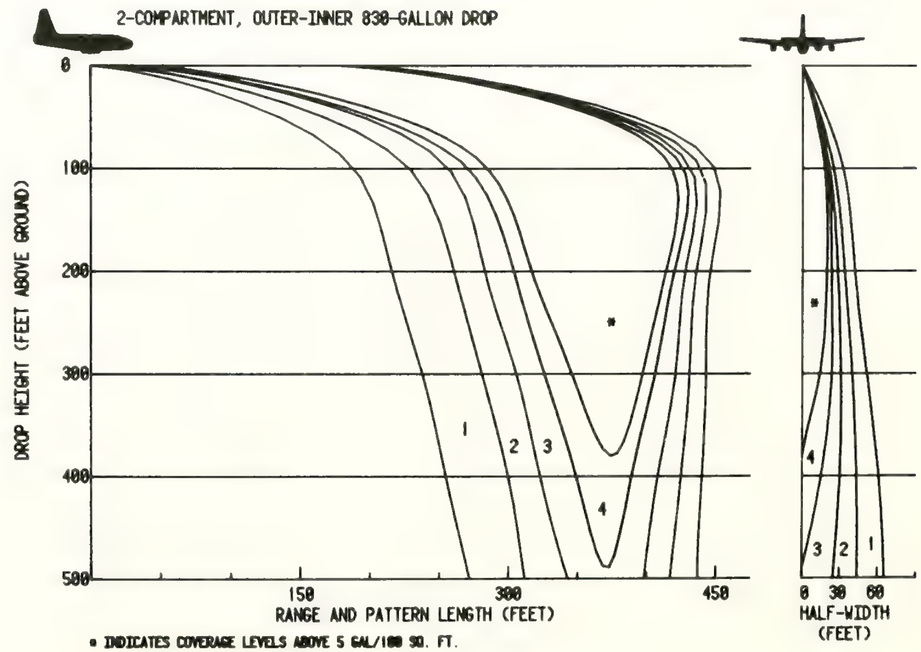
USE OF PATTERN FOOTPRINTS

Pattern footprints provide information on aircraft capability at various coverage levels. The presentation allows estimation of ground range from point of release to the center (deepest penetration) of the pattern. It shows where pattern coverage is relatively constant with increasing altitude, useful to develop width and increase operating safety, and where small increases in altitude cause rapid decreases in some coverage levels. The footprints also indicate, by comparison, the differences in operations related to retardant type.

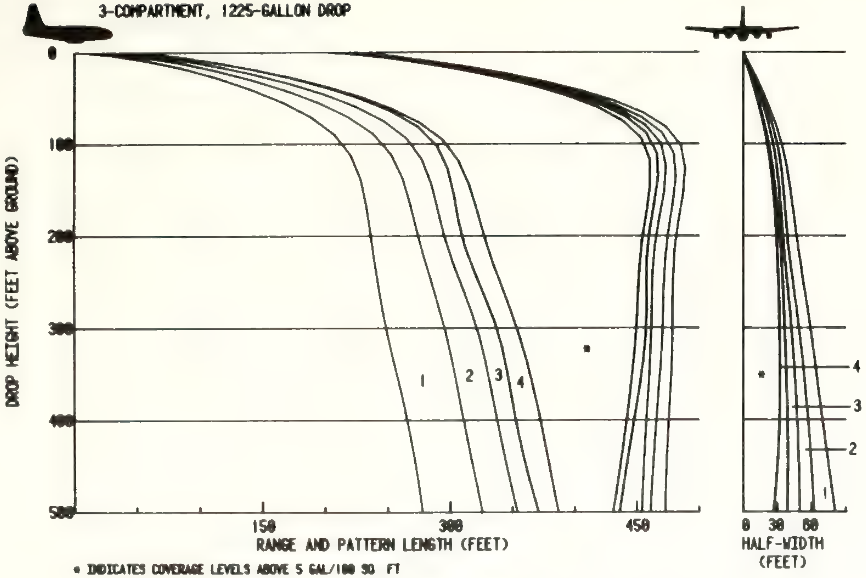
Pattern Coverage Characteristics - WATER-LIKE Retardants
Fire-Trol 100, Fire-Trol 931 (LC) and Water



- Drop Speed: 125 knots
- Coverage levels in gallons per 100 square feet



Pattern Coverage Characteristics - WATER-LIKE Retardants
Fire-Trol 100, Fire-Trol 931 (LC) and Water

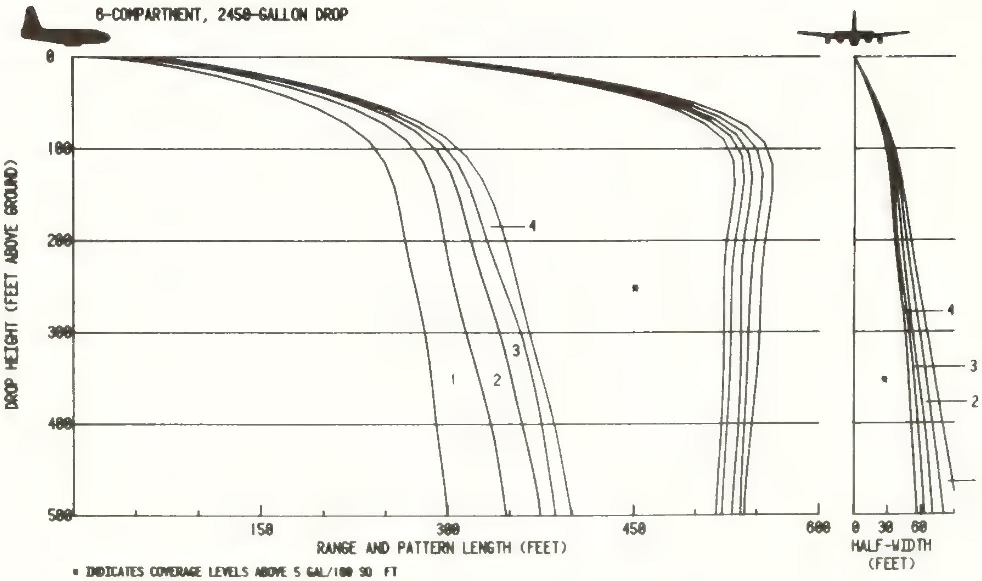


Recommended For:		
Coverage Level	Fuel Model[1] (1978 NFDRS)	Description
1	A, L, S	Annual and Perennial Western grasses, tundra
2	C, H, P, U	Tall grasses, Conifer (with grasses/forbs/needles and/or woody shrubs understory)
	E, R,	Hardwoods (winter and summer)
3	K, F[2], N, T	Light slash (conifer or hardwood), Intermediate brush (green), Sawgrass, Western woody shrubs
4	G	Shortneedle conifer (heavy dead litter)
6	D, Q, F[2]	Southern Rough, Alaska Black Spruce, Intermediate brush (cured)
Greater than 6	B, I, J, O	California mixed chaparral, Medium and heavy slash, High Pocosin

For creeping or smouldering fires reduction of one coverage level may be considered
[1] Fuel models considered to be in flammable condition
[2] Coverage level requirements for intermediate brush depend on its stage of curing

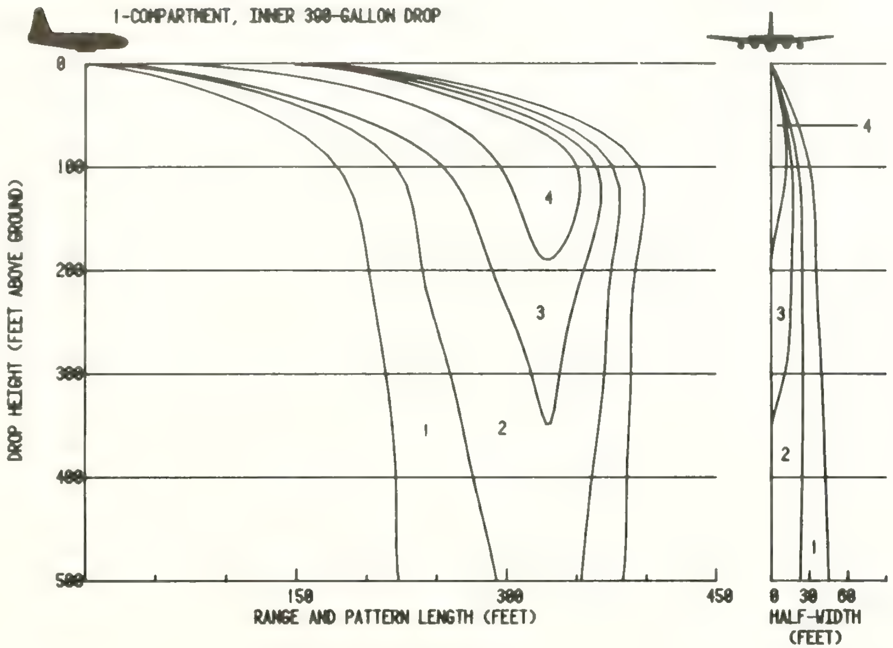
USE OF PATTERN FOOTPRINTS

Pattern footprints provide information on aircraft capability at various coverage levels. The presentation allows estimation of ground range from point of release to the center (deepest penetration) of the pattern. It shows where pattern coverage is relatively constant with increasing altitude, useful to develop width and increase operating safety, and where small increases in altitude cause rapid decreases in some coverage levels. The footprints also indicate, by comparison, the differences in operations related to retardant type.

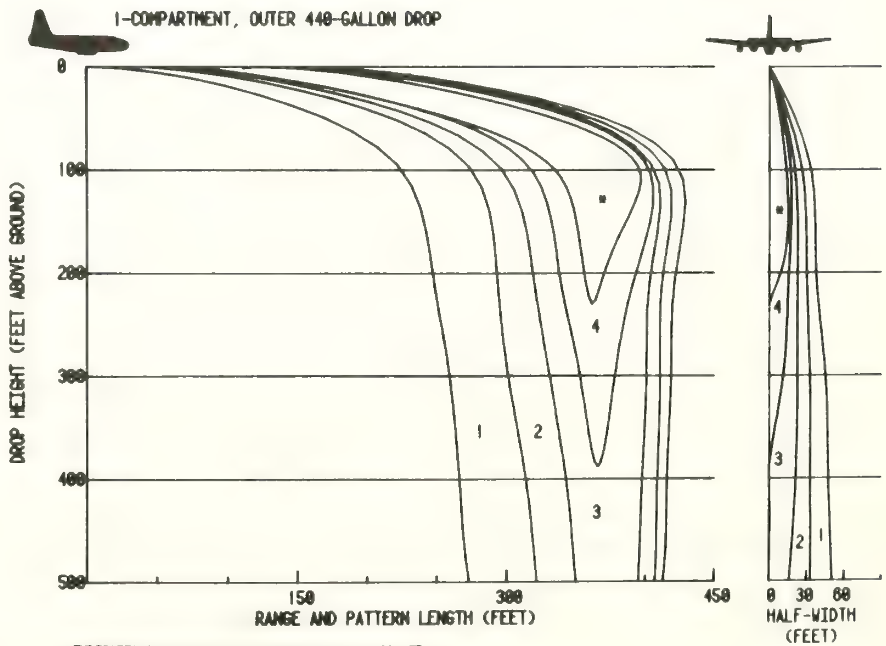


T07(4)

Pattern Coverage Characteristics - GUM-THICKENED Retardants
Phos-Chek XA, Gelgard and Gum-Thickened Fire-Trol 931 (LC)



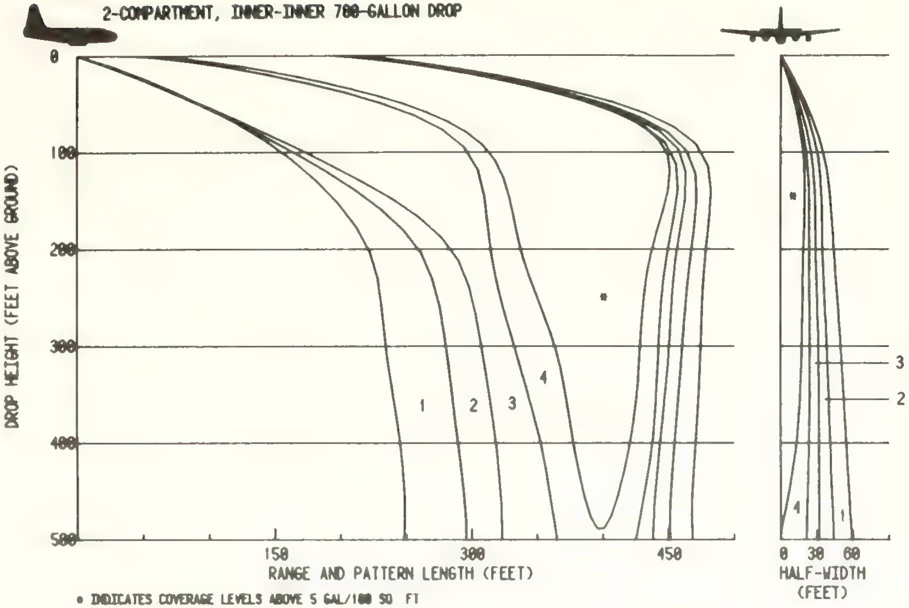
- Drop speed: 125 knots
- Coverage levels in gallons per 100 square feet



* INDICATES COVERAGE LEVELS ABOVE 5 GAL/100 SQ FT.

T07(5)

Pattern Coverage Characteristics - GUM-THICKENED Retardants
Phos-Chek XA, Gelgard and Gum-Thickened Fire-Trol 931 (LC)

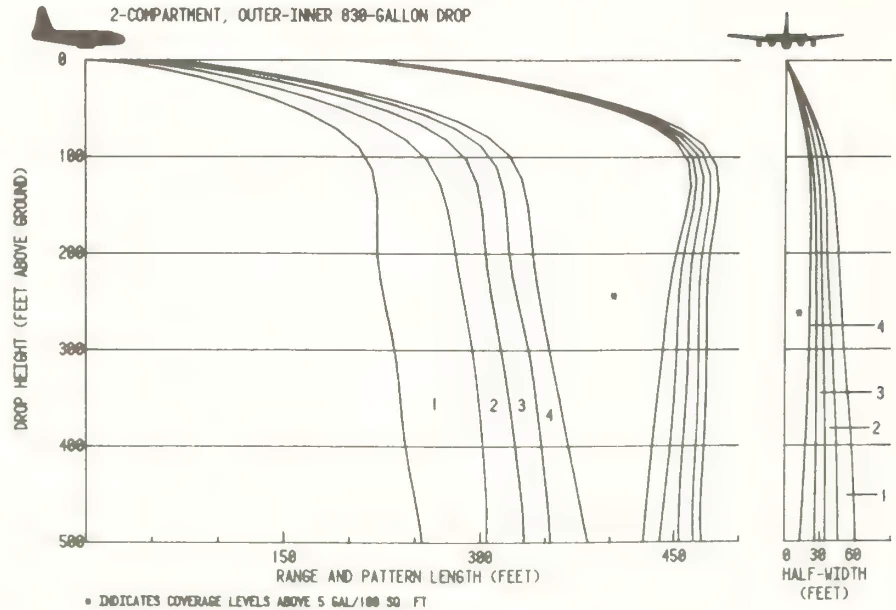


Recommended For:		
Coverage Level	Fuel Model[1] (1978 NFDRS)	Description
1	A, L, S	Annual and Perennial Western grasses, tundra
2	C, H, P, U E, R,	Tall grasses, Conifer (with grasses/forbs/needles and/or woody shrubs understory) Hardwoods (winter and summer)
3	K, F[2], N, T	Light slash (conifer or hardwood), Intermediate brush (green), Sawgrass, Western woody shrubs
4	G	Shortneedle conifer (heavy dead litter)
6	D, Q, F[2]	Southern Rough, Alaska Black Spruce, Intermediate brush (cured)
Greater than 6	B, I, J, O	California mixed chaparral, Medium and heavy slash, High Pocosin

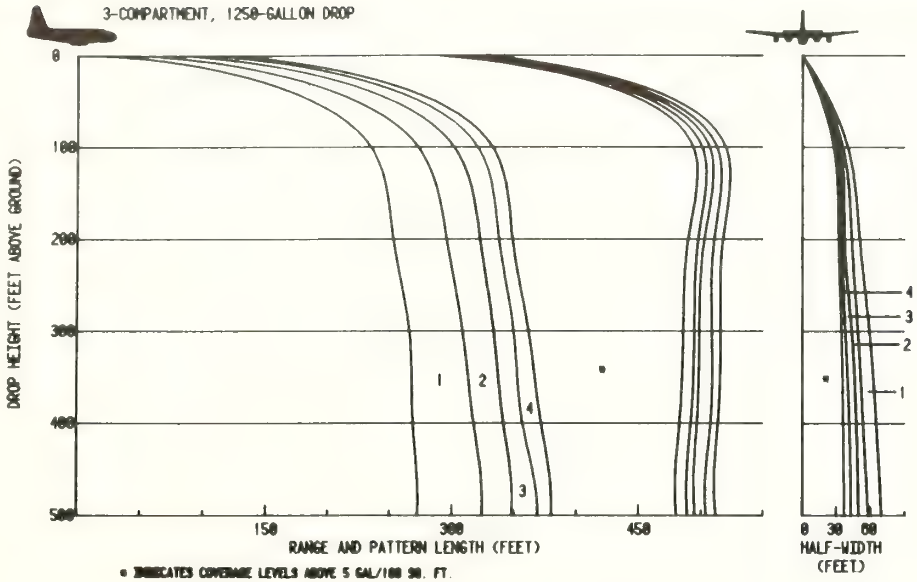
For creeping or smouldering fires reduction of one coverage level may be considered
[1] Fuel models considered to be in flammable condition
[2] Coverage level requirements for intermediate brush depend on its stage of curing

USE OF PATTERN FOOTPRINTS

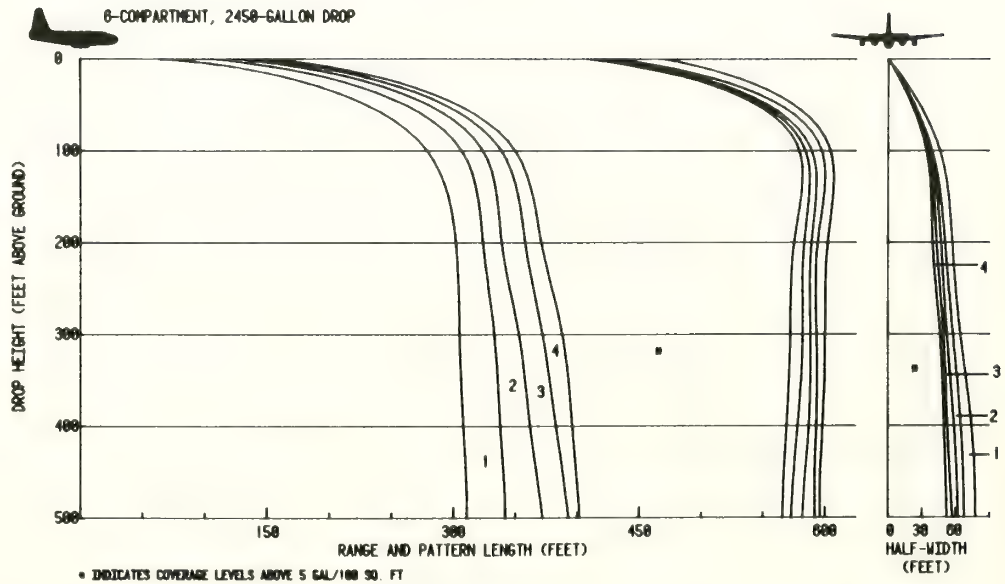
Pattern footprints provide information on aircraft capability at various coverage levels. The presentation allows estimation of ground range from point of release to the center (deepest penetration) of the pattern. It shows where pattern coverage is relatively constant with increasing altitude, useful to develop width and increase operating safety, and where small increases in altitude cause rapid decreases in some coverage levels. The footprints also indicate, by comparison, the differences in operations related to retardant type.



Pattern Coverage Characteristics - GUM-THICKENED Retardants
Phos-Chek XA, Gelgard and Gum-Thickened Fire-Trol 931 (LC)



- Drop speed: 125 knots
- Coverage levels in gallons per 100 square feet



Next page is T07(9)

USE OF THE BEST-STRATEGY CHARTS

(A) Select the charts for the retardant type to be employed in the operations. This will be GUM-THICKENED (such as Phos-Chek) or WATER-LIKE (such as Fire-Trol 100).

(B) Select the chart for the appropriate coverage level for fuel and fire situations in the area of operations.

Recommended For:		
Coverage Level	Fuel Model[1] (1978 NFDRS)	Description
1	A, L, S	Annual and Perennial Western grasses; tundra
2	C, H, P, U E, R,	Tall grasses. Conifer (with grasses/forbs/needles and/or woody shrubs understory) Hardwoods (winter and summer)
3	K, F[2], N, T	Light slash (conifer or hardwood); Intermediate brush (green); Sawgrass; Western woody shrubs
4	G	Shortneedle conifer (heavy dead litter)
6	D, Q, F[2]	Southern Rough; Alaska Black Spruce, Intermediate brush (cured)
Greater than 6	B, I, J, O	California mixed chaparral, Medium and heavy slash. High Pocosin

For creeping or smouldering fires reduction of one coverage level may be considered
[1] Fuel models considered to be in flammable condition
[2] Coverage level requirements for intermediate brush depend on its stage of curing

(C) Estimate the length of line required for a particular drop at the selected coverage level.

(D) Determine drop-height limits: (1) to assure aircraft safety in clearance of terrain features both before and after the planned release and (2) to protect ground personnel in close-support operations.

(E) Identify the region on the chart defined by the line-length, drop-height condition. This will identify the best release strategy to achieve the required coverage:

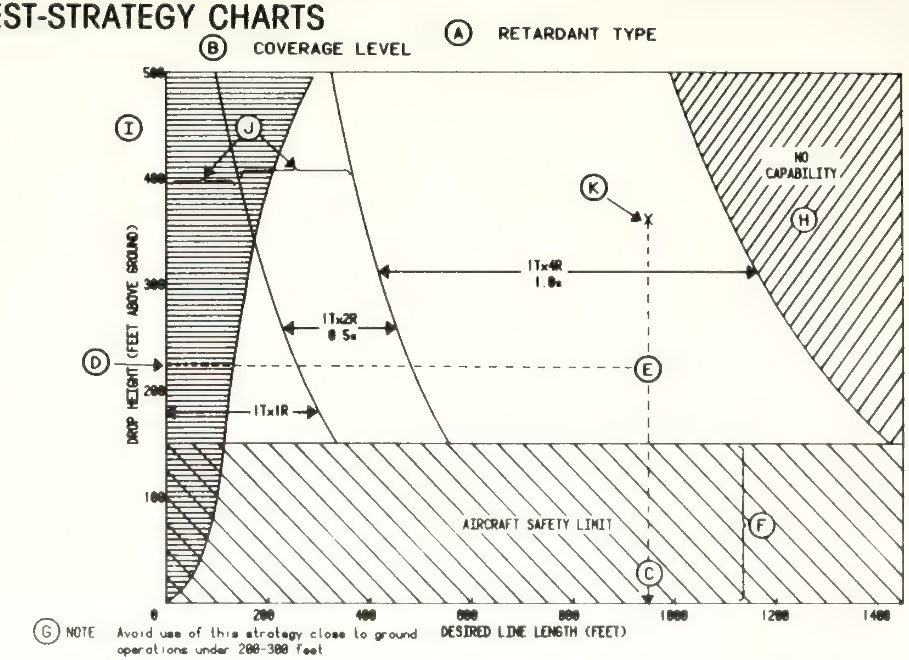
2T x 2R

1.2s

The number of tank compartments to be released at one time

The number of successive releases

The approximate interval between releases in seconds



(F) SAFETY LIMIT -- Usually expressed as a fuel clearance distance; will normally be at 150 feet above ground or greater depending on terrain or fuel features

(G) NOTES -- Indicate altitude limits for high-momentum drops potentially dangerous to ground personnel when used in close support or call out other recommendations or limitations for a particular strategy.

(H) LIMITS OF CAPABILITY -- The aircraft cannot produce, in a single pass, line-length greater than that defined by the limit curve.

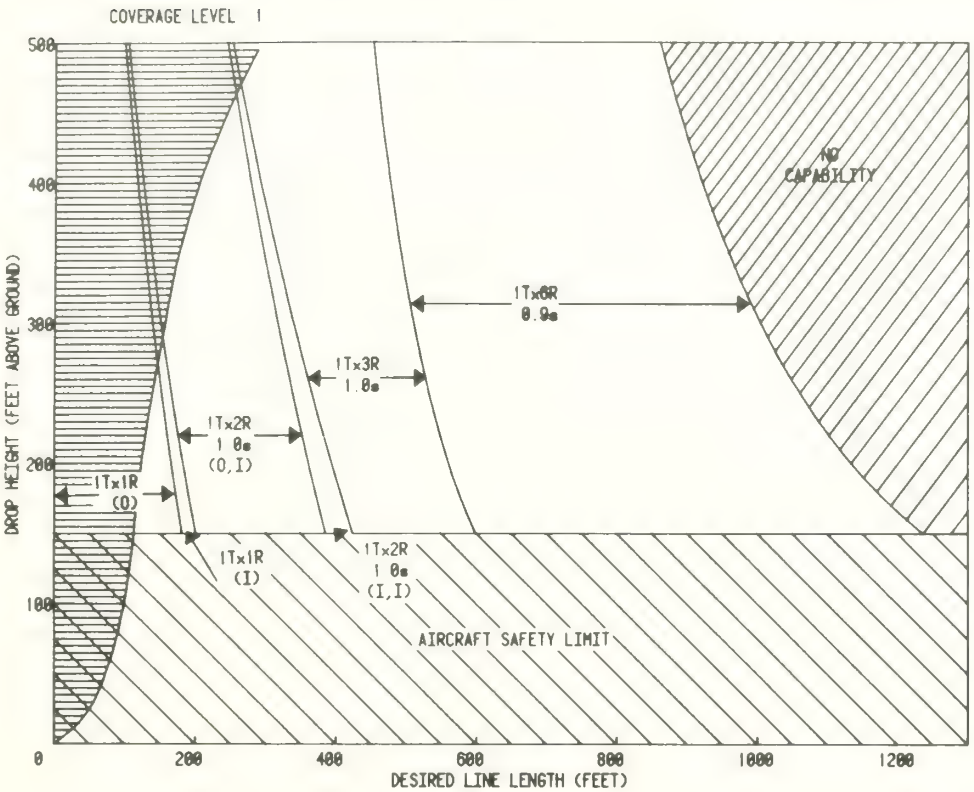
(I) REGION OF LIMITED ACCURACY -- The ability to place a pattern of the specified coverage level on a spot fire is doubtful if operations must be conducted in this region.

(J) OPERATING REGIONS -- Most efficient use of the available retardant and pattern controls will occur for the strategy listed. For more precise intervalometer settings see the detailed tables.

(K) If the desired drop is well within the line-building capability of the release strategy, consider flying higher. This will result in a wider pattern and increased safety.

T07(9)

Best Release Strategy - WATER-LIKE Retardants
Fire-Trol 100, Fire-Trol 931 (LC) and Water

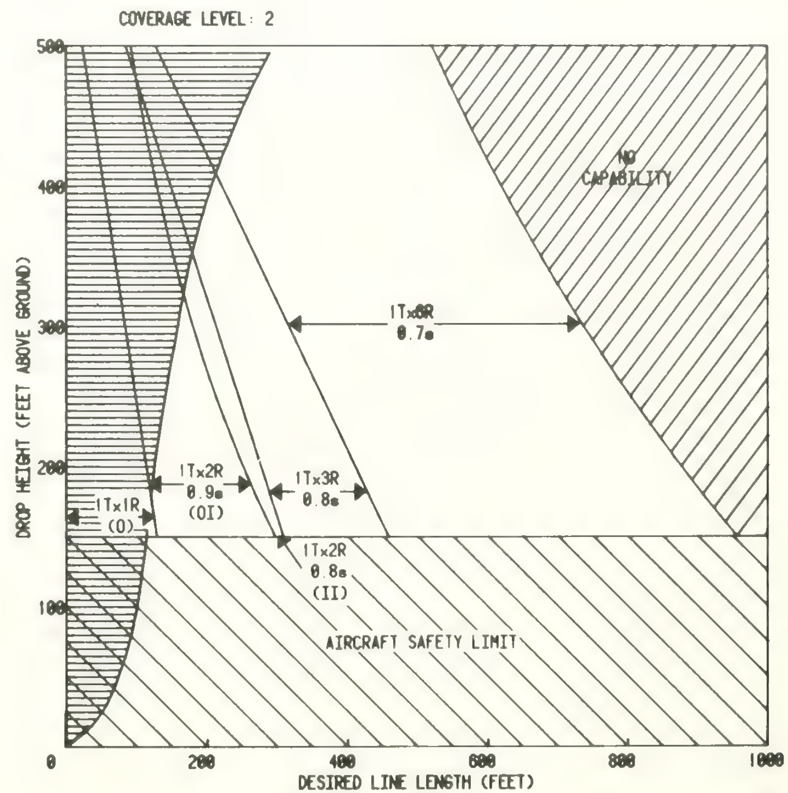


T - Tank compartments released at one time

R = Successive releases

s - seconds between successive releases

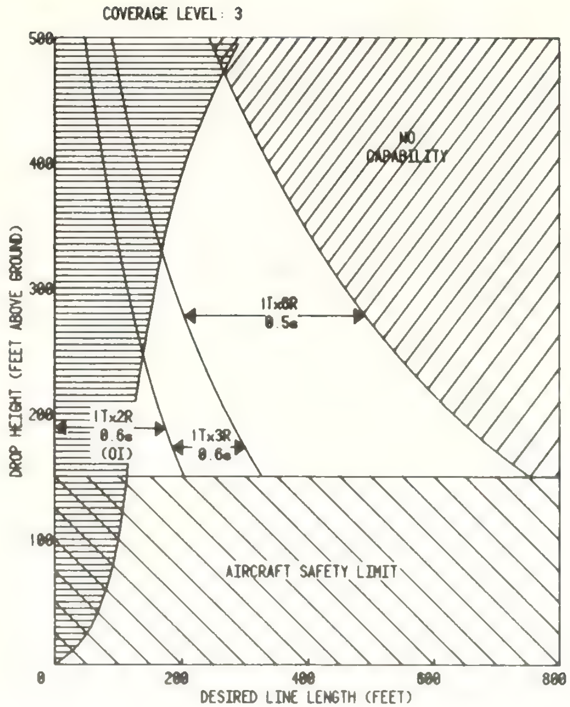
Region of limited accuracy in direct attack



NOTES: (1) Avoid one-compartment release close to ground operations under 180 feet.
(2) Avoid two-compartment release close to ground operations under 200 feet.
(3) Avoid three-compartment release close to ground operations under 220 feet.
(4) Avoid six-compartment release close to ground operations under 280 feet.

T07(10)

Best Release Strategy - WATER-LIKE Retardants
Fire-Trol 100, Fire-Trol 931 (LC) and Water



T = Tank compartments released at one time

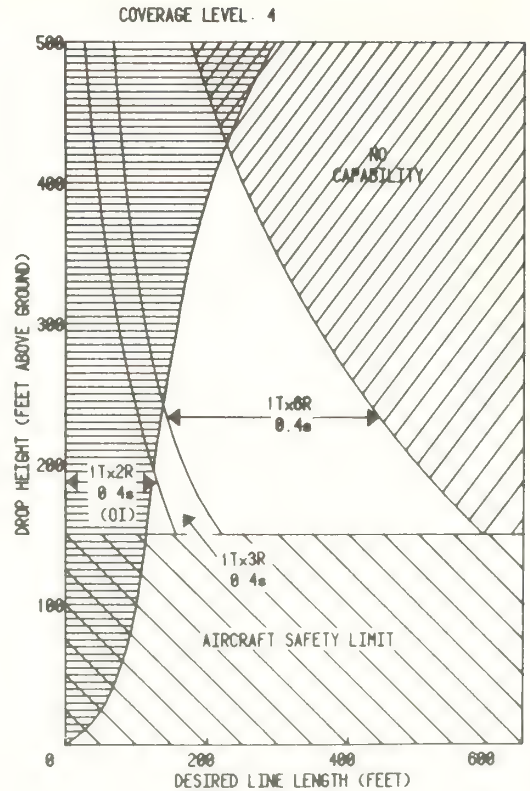
R = Successive releases

s = seconds between successive releases

▤ = Region of limited accuracy in direct attack

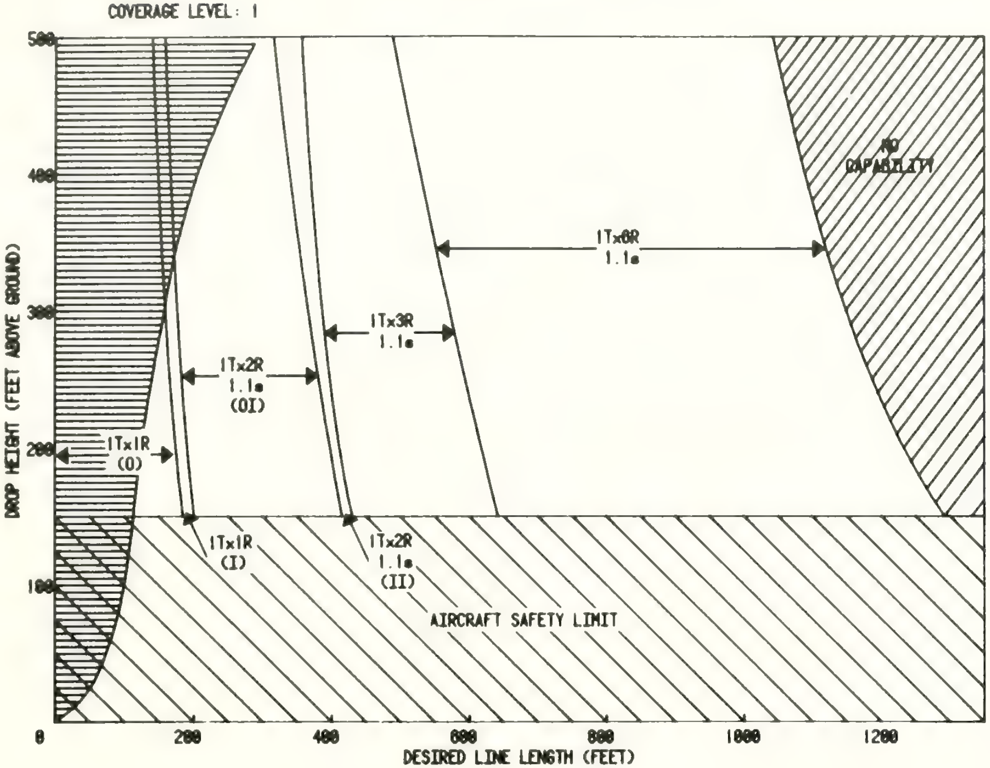
Recommended For:		
Coverage Level	Fuel Model[1] (1978 NFDRS)	Description
1	A, L, S	Annual and Perennial Western grasses, tundra
2	C, H, P, U	Tall grasses. Conifer (with grasses/forbs/needles and/or woody shrubs understory)
	E, R,	Hardwoods (winter and summer)
3	K, F[2], N, T	Light slash (conifer or hardwood). Intermediate brush (green). Sawgrass, Western woody shrubs
4	G	Shortneedle conifer (heavy dead litter)
6	D, Q, F[2]	Southern Rough, Alaska Black Spruce, Intermediate brush (cured)
Greater than 6	B, I, J, O	California mixed chaparral, Medium and heavy slash High Pocosin

For creeping or smouldering fires reduction of one coverage level may be considered
[1] Fuel models considered to be in flammable condition
[2] Coverage level requirements for intermediate brush depend on its stage of curing



T07(11)

Best Release Strategy - GUM-THICKENED Retardants
Phos-Chek XA, Gelgard and Gum-Thickened Fire-Trol 931 (LC)

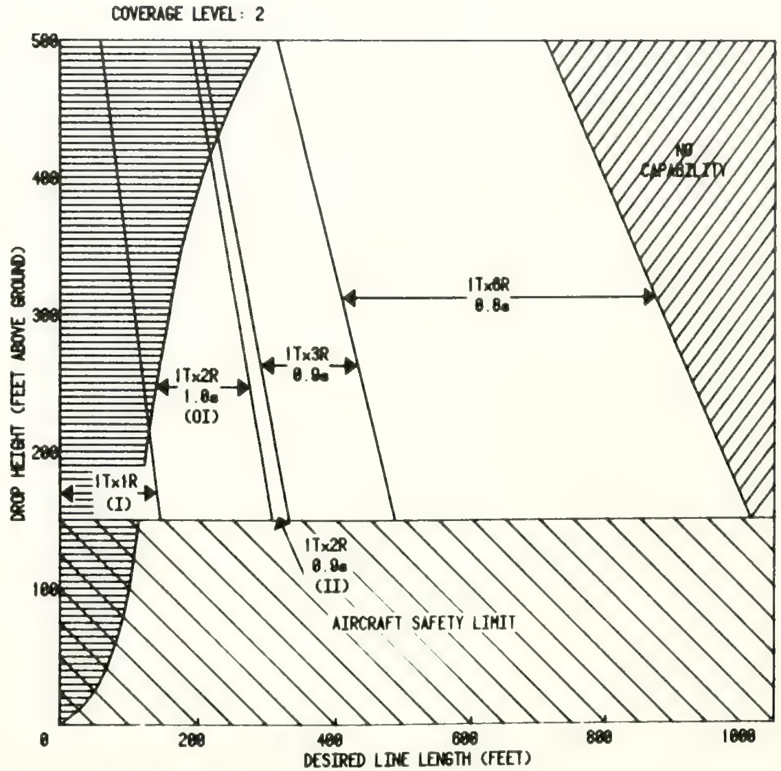


T = Tank compartments released at one time

R = Successive releases

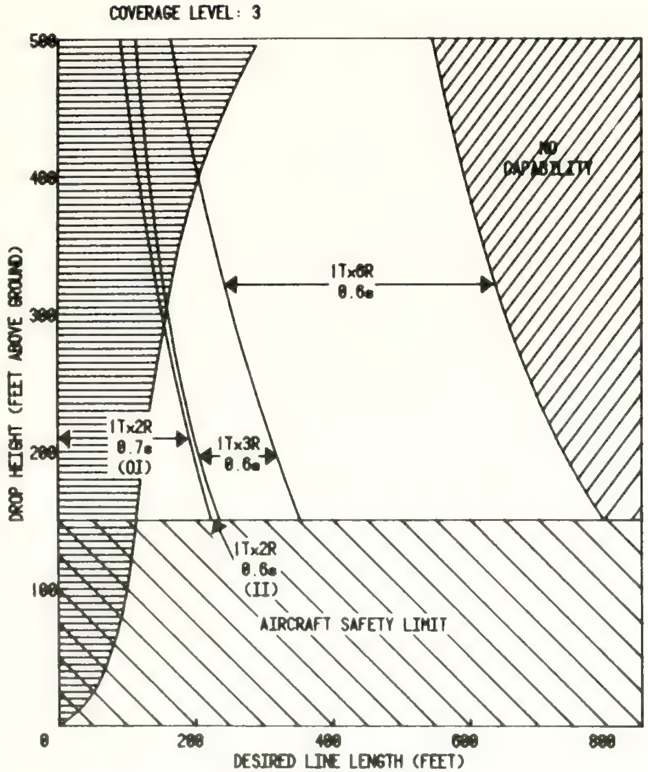
s = seconds between successive releases

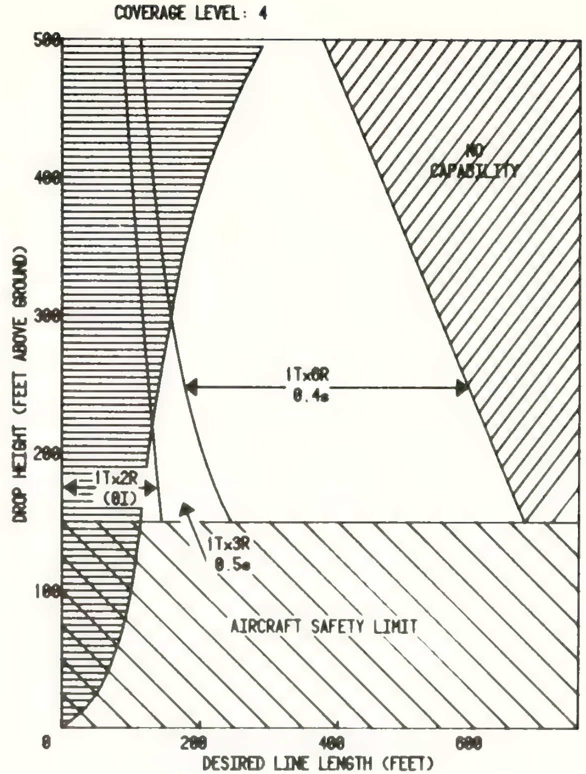
= Region of limited accuracy in direct attack



T07(12)

Best Release Strategy - GUM-THICKENED Retardants
Phos-Chek XA, Gelgard and Gum-Thickened Fire-Trol 931 (LC)





NOTES: (1) Avoid one-compartment release close to ground operations under 180 feet.
(2) Avoid two-compartment release close to ground operations under 200 feet.
(3) Avoid three-compartment release close to ground operations under 220 feet.
(4) Avoid six-compartment release close to ground operations under 280 feet.

T07(13)

Maximum Line Lengths/Tank-Opening Delays - WATER-LIKE Retardants
Fire-Trol 100, Fire-Trol 931 (LC) and Water

			LEVEL 1				LEVEL 2		LEVEL 3		LEVEL 4							
			COVERAGE (GALLONS 100 SQ.FT.)															
			0.5		1.0		2.0		3.0		4.0		6.0		8.0		10.0	
COMPARTMENTS RELEASED AT A TIME	DROP HT FT	NO. OF PATTERNS	MAX LENGTH (FT)	DELAY (SEC)	MAX LENGTH (FT)	DELAY (SEC)	MAX LENGTH (FT)	DELAY (SEC)	MAX LENGTH (FT)	DELAY (SEC)	MAX LENGTH (FT)	DELAY (SEC)	MAX LENGTH (FT)	DELAY (SEC)	MAX LENGTH (FT)	DELAY (SEC)	MAX LENGTH (FT)	DELAY (SEC)
ONE OUTER (O)	100	1	275	0.0	200	0.0	145	0.0	110	0.0	90	0.0	40	0.0	0	0.0	0	0.0
	200	1	225	0.0	165	0.0	115	0.0	75	0.0	45	0.0	0	0.0	0	0.0	0	0.0
	300	1	195	0.0	140	0.0	85	0.0	40	0.0	0	0.0	0	0.0	0	0.0	0	0.0
	400	1	170	0.0	115	0.0	55	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
	500	1	150	0.0	100	0.0	25	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
ONE INNER (I)	100	1	275	0.0	200	0.0	160	0.0	115	0.0	60	0.0	0	0.0	0	0.0	0	0.0
	200	1	240	0.0	185	0.0	110	0.0	45	0.0	0	0.0	0	0.0	0	0.0	0	0.0
	300	1	215	0.0	150	0.0	50	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
	400	1	190	0.0	125	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
	500	1	175	0.0	105	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
1 - 2 (O,I)	100	2	550	1.4	410	1.1	340	1.0	255	0.9	200	0.7	115	0.4	85	0.3	45	0.0
	200	2	465	1.3	360	1.0	250	0.9	165	0.6	120	0.4	75	0.3	15	0.1	0	0.0
	300	2	410	1.1	320	1.0	180	0.7	115	0.4	70	0.3	5	0.1	0	0.0	0	0.0
	400	2	375	1.1	280	0.9	130	0.6	75	0.3	45	0.1	0	0.0	0	0.0	0	0.0
	500	2	345	1.0	245	0.9	90	0.4	45	0.1	0	0.0	0	0.0	0	0.0	0	0.0
1 - 2 (I,I	100	2	555	1.4	455	1.2	340	1.0	285	0.8	205	0.6	115	0.0	65	0.0	5	0.0
	200	2	500	1.3	395	1.1	275	0.8	175	0.6	110	0.0	55	0.0	0	0.0	0	0.0
	300	2	450	1.2	340	1.0	210	0.6	100	0.0	50	0.0	0	0.0	0	0.0	0	0.0
	400	2	410	1.1	295	0.8	135	0.0	50	0.0	0	0.0	0	0.0	0	0.0	0	0.0
	500	2	370	1.0	250	0.7	100	0.0	10	0.0	0	0.0	0	0.0	0	0.0	0	0.0
	100	3	820	1.4	655	1.1	505	0.9	390	0.8	325	0.6	165	0.4	120	0.0	[illegible]	0.0
		6	1675	1.3	1385	1.1	1035	0.9	895	0.7	705	0.6	500	0.4	270	0.3	160	0.0
	200	3	735	1.3	560	1.0	410	0.8	270	0.6	165	0.4	110	0.0	85	0.0	60	0.0
		6	1500	1.3	1135	0.9	865	0.7	615	0.5	500	0.4	250	0.3	175	0.1	120	0.0
ONE	300	3	655	1.1	510	0.9	315	0.6	185	0.4	120	0.0	80	0.0	45	0.0	0	0.0
		6	1325	1.1	1005	0.9	725	0.6	440	0.4	350	0.3	165	0.1	120	0.0	115	0.0
(ALL COMB)	400	3	585	1.1	475	0.8	220	0.6	130	0.3	95	0.0	45	0.0	0	0.0	0	0.0
		6	1175	1.0	920	0.7	605	0.5	320	0.3	250	0.2	120	0.0	95	0.0	100	0.0
	500	3	520	0.9	455	0.8	135	0.0	100	0.0	65	0.0	0	0.0	0	0.0	0	0.0
		6	1040	0.9	860	0.8	505	0.4	225	0.1	175	0.1	100	0.0	70	0.0	40	0.0
TWO (O+I)	100	1	290	0.0	260	0.0	240	0.0	175	0.0	155	0.0	115	0.0	85	0.0	45	0.0
	200	1	270	0.0	230	0.0	175	0.0	145	0.0	115	0.0	75	0.0	0	0.0	0	0.0
	300	1	255	0.0	205	0.0	150	0.0	115	0.0	80	0.0	0	0.0	0	0.0	0	0.0
	400	1	235	0.0	185	0.0	125	0.0	85	0.0	40	0.0	0	0.0	0	0.0	0	0.0
	500	1	220	0.0	165	0.0	105	0.0	55	0.0	0	0.0	0	0.0	0	0.0	0	0.0
TWO (I+I)	100	1	305	0.0	270	0.0	215	0.0	195	0.0	160	0.0	115	0.0	65	0.0	0	0.0
	200	1	285	0.0	235	0.0	185	0.0	145	0.0	110	0.0	55	0.0	0	0.0	0	0.0
	300	1	265	0.0	210	0.0	155	0.0	100	0.0	50	0.0	0	0.0	0	0.0	0	0.0
	400	1	250	0.0	190	0.0	135	0.0	50	0.0	0	0.0	0	0.0	0	0.0	0	0.0
	500	1	235	0.0	175	0.0	100	0.0	10	0.0	0	0.0	0	0.0	0	0.0	0	0.0
	100	2	635	1.6	530	1.3	450	1.1	360	0.9	340	0.9	265	0.7	200	0.6	145	0.4
		3	965	1.6	795	1.3	700	1.1	540	0.9	510	0.9	420	0.7	340	0.6	255	0.4
	200	2	560	1.4	480	1.1	380	0.9	305	0.7	255	0.7	170	0.4	115	0.4	90	0.3
		3	850	1.4	725	1.1	575	0.9	470	0.7	425	0.7	280	0.4	225	0.4	165	0.3
TWO	300	2	520	1.3	435	1.1	320	0.9	250	0.7	185	0.6	115	0.3	60	0.3	35	0.0
		3	785	1.3	660	1.1	485	0.9	400	0.7	340	0.6	195	0.3	145	0.3	115	0.0
(ALL COMB)	400	2	485	1.1	390	0.9	270	0.6	200	0.6	135	0.4	75	0.1	25	0.0	0	0.0
		3	735	1.1	590	0.9	420	0.6	335	0.6	255	0.4	140	0.1	95	0.0	100	0.0
	500	2	465	1.1	340	0.9	230	0.6	145	0.4	100	0.3	45	0.0	0	0.0	0	0.0
		3	700	1.1	520	0.9	370	0.6	265	0.4	170	0.3	90	0.0	70	0.0	40	0.0
	100	1	300	0.0	270	0.0	230	0.0	200	0.0	175	0.0	145	0.0	120	0.0	100	0.0
		2	630	1.7	550	1.4	480	1.2	435	1.1	380	1.0	305	0.8	275	0.7	235	0.7
	200	1	280	0.0	245	0.0	200	0.0	170	0.0	150	0.0	110	0.0	85	0.0	60	0.0
		2	570	1.5	515	1.3	425	1.1	350	0.9	315	0.9	255	0.7	200	0.6	165	0.5
THREE	300	1	265	0.0	230	0.0	175	0.0	140	0.0	120	0.0	80	0.0	45	0.0	0	0.0
		2	540	1.5	475	1.2	375	1.0	300	0.8	265	0.7	205	0.6	145	0.5	120	0.0
(ALL COMB)	400	1	250	0.0	210	0.0	155	0.0	120	0.0	95	0.0	45	0.0	0	0.0	0	0.0
		2	515	1.3	440	1.1	330	0.9	265	0.7	220	0.6	155	0.5	105	0.2	100	0.0
	500	1	235	0.0	195	0.0	135	0.0	100	0.0	65	0.0	0	0.0	0	0.0	0	0.0
		2	495	1.3	400	1.0	290	0.8	235	0.6	185	0.5	105	0.2	75	0.2	40	0.0
SIX (ALL COMB)	100	1	530	0.0	315	0.0	275	0.0	250	0.0	235	0.0	200	0.0	170	0.0	160	0.0
	200	1	340	0.0	290	0.0	250	0.0	220	0.0	200	0.0	170	0.0	145	0.0	130	0.0
	300	1	305	0.0	270	0.0	225	0.0	195	0.0	170	0.0	140	0.0	120	0.0	115	0.0
	400	1	290	0.0	255	0.0	205	0.0	175	0.0	150	0.0	120	0.0	95	0.0	100	0.0
	500	1	280	0.0	240	0.0	190	0.0	155	0.0	135	0.0	100	0.0	70	0.0	40	0.0

T07(14)

Maximum Line Lengths/Tank-Opening Delays - GUM-THICKENED Retardants
Phos-Chek XA, Gelgard and Gum-Thickened Fire-Trol 931 (LC)

COMPARTMENTS RELEASED AT A TIME	DROP HT FT	NO. OF PATTERNS	LEVEL 1				LEVEL 2		LEVEL 3		LEVEL 4							
			COVERAGE (GALLONS/100 SQ.FT.)															
			0.5		1.0		2.0		3.0		4.0		6.0		8.0		10.0	
			MAX LENGTH (FT)	DELAY (SEC)	MAX LENGTH (FT)	DELAY (SEC)	MAX LENGTH (FT)	DELAY (SEC)	MAX LENGTH (FT)	DELAY (SEC)	MAX LENGTH (FT)	DELAY (SEC)	MAX LENGTH (FT)	DELAY (SEC)	MAX LENGTH (FT)	DELAY (SEC)	MAX LENGTH (FT)	DELAY (SEC)
	100	1	285	0.0	200	0.0	145	0.0	110	0.0	90	0.0	40	0.0	0	0.0	0	0.0
	200	1	260	0.0	175	0.0	120	0.0	85	0.0	55	0.0	0	0.0	0	0.0	0	0.0
ONE OUTER (O)	300	1	240	0.0	160	0.0	110	0.0	70	0.0	25	0.0	0	0.0	0	0.0	0	0.0
	400	1	220	0.0	150	0.0	95	0.0	55	0.0	0	0.0	0	0.0	0	0.0	0	0.0
	500	1	200	0.0	140	0.0	85	0.0	45	0.0	0	0.0	0	0.0	0	0.0	0	0.0
	100	1	280	0.0	215	0.0	160	0.0	115	0.0	60	0.0	0	0.0	0	0.0	0	0.0
	200	1	260	0.0	190	0.0	135	0.0	65	0.0	0	0.0	0	0.0	0	0.0	0	0.0
ONE INNER (I)	300	1	245	0.0	175	0.0	110	0.0	20	0.0	0	0.0	0	0.0	0	0.0	0	0.0
	400	1	230	0.0	165	0.0	85	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
	500	1	215	0.0	160	0.0	60	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
	100	2	550	1.4	435	1.3	340	1.0	255	0.9	200	0.7	120	0.3	85	0.0	45	0.0
	200	2	525	1.4	400	1.1	290	1.0	195	0.7	135	0.4	85	0.3	20	0.0	0	0.0
1×2 (O,I)	300	2	490	1.3	365	1.1	255	0.9	150	0.6	115	4.0	55	0.1	0	0.0	0	0.0
	400	2	460	1.3	340	1.0	225	0.7	130	0.6	100	0.3	30	0.1	0	0.0	0	0.0
	500	2	435	1.3	315	1.0	190	0.7	120	0.6	85	0.4	0	0.0	0	0.0	0	0.0
	100	2	570	1.5	460	1.2	350	1.0	285	0.8	205	0.6	115	0.0	65	0.0	5	0.0
	200	2	535	1.4	410	1.1	315	0.9	205	0.6	140	0.0	65	0.0	0	0.0	0	0.0
1×2 (I,I)	300	2	505	1.3	385	1.0	275	0.8	160	0.5	110	0.0	25	0.0	0	0.0	0	0.0
	400	2	475	1.3	370	1.0	240	0.7	130	0.0	85	0.0	0	0.0	0	0.0	0	0.0
	500	2	450	1.2	360	1.0	205	0.6	115	0.0	60	0.0	0	0.0	0	0.0	0	0.0
	100	3	825	1.4	665	1.2	510	0.9	395	0.8	325	0.6	165	0.3	125	0.1	100	0.0
		6	1675	1.3	1385	1.1	1060	0.9	895	0.7	715	0.6	545	0.3	295	0.1	175	0.1
	200	3	785	1.4	620	1.1	460	0.9	315	0.6	205	0.4	125	0.0	95	0.0	70	0.0
		6	1540	1.3	1235	1.1	970	0.8	735	0.6	630	0.5	300	0.3	190	0.1	140	0.0
ONE	300	3	745	1.2	570	1.1	410	0.8	255	0.5	155	0.5	105	0.0	75	0.0	45	0.0
		6	1470	1.1	1150	1.0	880	0.7	650	0.5	545	0.5	215	0.1	190	0.1	120	0.0
(ALL COMB)	400	3	705	1.2	530	0.9	365	0.7	205	0.5	135	0.0	90	0.0	60	0.0	20	0.0
		6	1425	1.1	1090	0.9	795	0.7	590	0.5	460	0.4	175	0.1	140	0.0	115	0.0
	500	3	665	1.2	490	0.9	315	0.6	165	0.5	120	0.0	80	0.0	45	0.0	0	0.0
		6	1390	1.1	1045	0.9	705	0.6	545	0.4	375	0.3	150	0.1	120	0.0	100	0.0
	100	1	310	0.0	265	0.0	215	0.0	180	0.0	155	0.0	120	0.0	85	0.0	45	0.0
	200	1	290	0.0	255	0.0	190	0.0	160	0.0	135	0.0	85	0.0	20	0.0	0	0.0
TWO (O+I)	300	1	280	0.0	240	0.0	175	0.0	145	0.0	115	0.0	55	0.0	0	0.0	0	0.0
	400	1	275	0.0	230	0.0	165	0.0	130	0.0	100	0.0	0	0.0	0	0.0	0	0.0
	500	1	270	0.0	215	0.0	160	0.0	120	0.0	85	0.0	0	0.0	0	0.0	0	0.0
	100	1	335	0.0	320	0.0	300	0.0	285	0.0	160	0.0	115	0.0	65	0.0	5	0.0
	200	1	300	0.0	260	0.0	210	0.0	175	0.0	140	0.0	65	0.0	0	0.0	0	0.0
TWO (I+I)	300	1	290	0.0	240	0.0	180	0.0	140	0.0	110	0.0	25	0.0	0	0.0	0	0.0
	400	1	280	0.0	225	0.0	165	0.0	130	0.0	85	0.0	0	0.0	0	0.0	0	0.0
	500	1	275	0.0	220	0.0	155	0.0	115	0.0	60	0.0	0	0.0	0	0.0	0	[illegible]
	100	2	640	1.6	565	1.4	465	1.1	385	1.0	340	0.9	265	0.7	200	0.6	145	0.6
		3	975	1.6	870	1.4	705	1.1	580	0.9	515	0.9	435	0.7	340	0.6	305	0.6
	200	2	605	1.6	525	1.3	410	1.0	345	0.9	285	0.7	200	0.6	150	0.4	95	0.3
		3	925	1.6	800	1.3	615	1.0	515	0.9	455	0.7	335	0.6	245	0.4	180	0.3
TWO	300	2	590	1.4	500	1.3	375	1.0	310	0.9	255	0.7	160	0.4	120	0.3	75	0.1
		3	900	1.4	760	1.3	570	0.9	475	0.8	405	0.7	275	0.4	190	0.3	135	0.1
(ALL COMB)	400	2	575	1.4	480	1.1	350	0.9	285	0.7	225	0.6	130	0.4	90	0.3	55	0.0
		3	880	1.4	730	1.1	540	0.9	450	0.7	370	0.6	230	0.4	155	0.3	115	0.0
	500	2	565	1.4	465	1.1	335	0.9	260	0.7	205	0.6	110	0.3	65	0.1	35	0.0
		3	865	1.4	710	1.1	515	0.9	425	0.7	335	0.6	200	0.3	130	[illegible]	[illegible]	[illegible]
	100	1	330	0.0	285	0.0	240	0.0	205	0.0	180	0.0	145	0.0	120	[illegible]	[illegible]	[illegible]
		2	660	1.7	570	1.5	515	1.3	450	1.2	385	1.0	315	0.9	275	[illegible]	35	[illegible]
	200	1	310	1.0	265	0.0	215	0.0	180	0.0	160	0.0	125	0.0	95	0.0	[illegible]	[illegible]
		2	625	1.6	555	1.4	460	1.2	395	1.0	340	0.9	285	0.8	225	0.6	195	0.6
THREE	300	1	295	1.0	250	0.0	200	0.0	165	0.0	145	0.0	105	0.0	75	0.0	45	0.0
		2	605	1.6	535	1.4	430	1.1	365	1.0	315	0.9	255	0.7	195	[illegible]	160	0.5
(ALL COMB)	400	1	290	0.0	245	0.0	190	0.0	155	0.0	135	0.0	90	[illegible]	60	0.0	[illegible]	0.0
		2	595	1.6	520	1.4	410	1.1	345	0.9	295	0.8	225	0.6	120	[illegible]	130	0.4
	500	1	280	0.0	240	0.0	180	0.0	150	0.0	120	0.0	80	0.0	45	[illegible]	0	0.0
		2	585	1.5	500	1.3	390	1.0	325	0.9	280	0.8	205	0.6	155	[illegible]	[illegible]	[illegible]
	100	1	545	0.0	325	0.0	290	0.0	265	0.0	245	0.0	210	0.0	180	[illegible]	[illegible]	0.0
	200	1	370	0.0	300	0.0	270	0.0	250	0.0	225	0.0	185	0.0	155	[illegible]	140	0.0
SIX (ALL COMB)	300	1	335	0.0	295	0.0	260	0.0	235	0.0	210	0.0	165	0.0	140	[illegible]	[illegible]	0.0
	400	1	320	0.0	290	0.0	255	0.0	225	0.0	195	0.0	155	0.0	130	[illegible]	115	0.0
	500	1	310	0.0	285	0.0	250	0.0	210	0.0	180	[illegible]	145	0.0	[illegible]	[illegible]	[illegible]	0.0

NOTE: Delivery below 150 feet is not recommended! Line-length policies for these guides were generated at a lower limit of 100 feet for engineering purposes in developing footprints and Best Strategy charts. They are presented here for information only. Line lengths for intermediate altitudes can be estimated by interpolation.

NOTE: Low-altitude line lengths tend to show a slight advantage for water-like retardants that is not necessarily supported by field data. The advantage of gum-thickened over water-like retardants increases rapidly under less-than-ideal conditions.

T07(15)

TECHNICAL DATA

BLACK HILLS/ROSENBALM TANKED[1]
P2V-5 AIRCRAFT

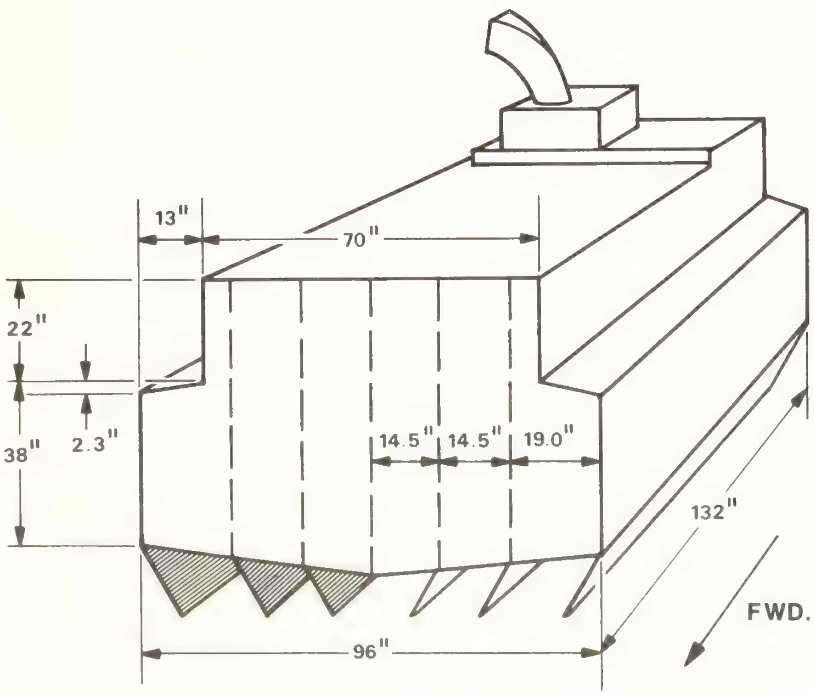
Compartment #	1				2				3				4				5				6			
# of Compartments Dropped at One Time	1	2	3	6	1	2	3	6	1	2	3	6	1	2	3	6	1	2	3	6	1	2	3	6
Door Opening Time (sec.)	0.36	0.53	0.55	0.60	0.34	0.36	0.37	0.39	0.34	0.36	0.37	0.39	0.34	0.36	0.37	0.39	0.34	0.36	0.37	0.39	0.36	0.53	0.55	0.60
Vent Area (sq. ft.)	1.28	0.64	0.43	0.21	1.28	0.64	0.43	0.21	1.28	0.64	0.43	0.21	1.28	0.64	0.43	0.21	1.28	0.64	0.43	0.21	1.28	0.64	0.43	0.21
Door Area (sq. ft.)	12.25				8.75				8.75				8.75				8.75				12.25			
Door LxW (ft)	10.50x1.16				10.50x0.83				10.50x0.83				10.50x0.83				10.50x0.83				10.50x1.16			
Door Opening Angle (deg)	89				87				87				87				87				89			
Volume (gal)	442				392				392				392				392				442			

(1) Tanker 07, N96271, SN 131434, static tested June 1979 by NFFL

Other applicapable aircraft are: Tanker 06, N9855F, SN 131445

Typical Single-Compartment
Flow Rate (gal/sec)

Time (sec)	Number of Compartments Released at One Time							
	1 (O)	1 (I)	2 (O)	2 (I)	3 (O)	3 (I)	6 (O)	6 (I)
0.05	184	106	70	232	174	91	161	218
0.10	269	419	267	361	303	106	294	311
0.15	381	433	438	415	474	292	492	467
0.20	854	539	939	598	950	403	1123	492
0.25	1250	554	1208	626	1133	513	1246	573
0.30	1206	627	1201	626	1156	703	1173	652
0.35	1136	627	1205	618	1114	678	1153	633
0.40	1180	627	1166	597	1082	683	1154	614
0.45		597		590		700		614
0.50		597		602		684		614
0.55		597		610		633		619
0.60		698				664		663
Test No.	11-16	11-3	11-7	11-7	11-10	11-10	11-12	11-13
Compartment No.	6	5	6	5	6	5	6	5



T07(17)

APPENDIX D: BASIC PROGRAMS

PATSUM	Adds dissimilar tanks.
LLDELAY.TAB	Tabulates line length and delay data.
LDR WIDTH	Calculates line length down range and pattern width from PATSIM.
BESTSTRAT.DAT	Data portion of best strategy plot.
BS Plot	Plots best strategy graphs.
SMOOTHFOOT	Smooths footprint data prior to the use of FINALFOOT.
FINAL FOOT	Plots footprint graphs.

PATSUM

PATSUM is used to add nonequal patterns to simulate trail drops.

```
100 PRINT "patadd for 2 DISSIMILAR tanks
105 SET DIA COL 3 | SET TEX COL 14 | SET TEX SIZ 4.0 | SET TEX STY 0
106 T$ = CHR$(27)
107 T$ = T$ & "MQ1" | T$ = "echo " & T$
108 CALL T$
109 INPUT PROMPT "what is the title? ":Tit$
110 INPUT PROMPT "what is the airspeed? ":Knots
120 DIM Valin1[56],Valin2[56],Itc[16]
130 DIM Tp[13440],Lcon[9],Conv[9],Aa[8],Sing1[1680],Lcmax[9],Xdel[9]
135 DIM Sing2[1680],Singx[1680]
140 DATA 0.5,1,2,3,4,6,8,10,12 | RESTORE 140
141 Itc = 0 | Itc[1] = 1 | Itc[2] = 1 | Itc[4] = 1 | Itc[8] = 1 | Itc[16] = 1
150 FOR I = 1 TO 9 | READ Conv[I] | NEXT I
160 PRINT "ENTER DATA FOR DROP 1 CENTER (ROW 14) ROW ENTER -1 TO STOP"
170 Valin1 = 0 | Valin2 = 0
180 FOR I = 1 TO 56 | PRINT "ENTER VALUE FOR ROW ";I
190   INPUT Q | IF Q<0 THEN EXIT TO 200 | Valin1[I] = Q | NEXT I
200 Npts1 = I-1
210 PRINT "ENTER DATA FOR DROP 2 CENTER (COL 14) COLUMN  ENTER -1 TO STOP"
220 FOR I = 1 TO 56 | PRINT "ENTER VALUE FOR ROW ";I
230   INPUT Q | IF Q<0 THEN EXIT TO 240 | Valin2[I] = Q | NEXT I
240 Npts2 = I-1
250 Jfirst = 0
260 Lalt = 0
261 Ialt = 1
270 Mcell = 5 ! LENGTH OF SUBCELL
280 Mstcl = 3 ! NUMBER OF SUBCELLS TO START
290 Mlncl = 6 ! NUMBER OF SUBCELLS TO A CELL
300 Fps = Knots*1.68781
310 Delt = 0.1 ! LENGTH (SEC) OF INTERVAL
320 Fpdel = Fps*Delt
330 Idcell = Fpdel/Mcell+0.5 ! COMPUTE NUMBER OF CELLS PER INTERVAL
340 REM EXPAND SINGLE PATTERN
350 Nto1 = Npts1+2 | Nto2 = Npts2+2
355 Qnext1 = 0 | Qnext2 = 0 | Xlastd1 = 0 | Xlastd2 = 0 | Xnextd1 = Mstcl | Xnextd2 = Mstcl
360 FOR I = 1 TO Nto1
370   Qlast1 = Qnext1
380   Qnext1 = Valin1[I]
390   Slope1 = (Qnext1-Qlast1)/(Xnextd1-Xlastd1)
400   Jx1 = Xlastd1+1
410   FOR J = Jx1 TO Xnextd1 | Sing1[J] = Qlast1+(J-Xlastd1)*Slope1 | NEXT J
420   Xlastd1 = Xnextd1
430   Xnextd1 = Xnextd1+Mlncl
```

```
440 NEXT I
450 Lsp1 = Npts1*Mlncl+Mlncl/2
460 Nintv1 = Lsp1/Idcell+1
470 REM SINGLE PATTERN 1 IS EXPANDED
480 FOR I = 1 TO Nto2
490   Qlast2 = Qnext2
500   Qnext2 = Valin2[I]
510   Slope2 = (Qnext2-Qlast2)/(Xnextd2-Xlastd2)
520   Jx2 = Xlastd2+1
530   FOR J = Jx2 TO Xnextd2 | Sing2[J] = Qlast2+(J-Xlastd2)*Slope2 | NEXT J
540   Xlastd2 = Xnextd2
550   Xnextd2 = Xnextd2+Mlncl
560 NEXT I
570 Lsp2 = Npts2*Mlncl+Mlncl/2
580 Nintv2 = Lsp2/Idcell+1
590 REM SINGLE PATTERN 2 IS EXPANDED
1000 REM ROUTINE TO ADD TOGETHER PATTERNS
1001 CLEAR
1002 Xpace = 1
1005 MOVE 0,95 | SET TEXT COLOR 1 | TEXT Tit$
1010 Ntank1 = 0
1015 Xdel = 0 | Lcmax = 0
1020 FOR Jj = 1 TO 16
1030   Ntank1 = Ntank1+1
1040   Xdel = 0 | Lcmax = 0
1050   IF Itc[Jj]<>1 THEN 2000
1051   K = 1
1052   GOSUB 5000
1060   FOR Jr = 1 TO Nintvx
1065     SET DIALOG COLOR 13 | PRINT Jr;" ";Nintvx | SET DIALOG COLOR 3
1070     J = Jr-1
1080     Idisp = J*Idcell
1090     Dly = J*Delt
1100     Maxl = Lspx+(Ntank1-1)*Idisp
1110     Tp = 0
1120     Idat = 0
1130     FOR K = 1 TO Ntank1
1135       GOSUB 5000
1140       FOR K1 = 1 TO Lspx
1150         Kk = K1+Idat
1160         Tp[Kk] = Tp[Kk]+Singx[K1]
1170       NEXT K1
1180       Idat = Idat+Idisp
1190     NEXT K
1200     REM ROUTINE TO COMPUTE LENGTHS
1205     SET TEXT COLOR 13
1210     Lcon = 0
1220     FOR I = 1 TO Maxl
1230       FOR J = 1 TO 9
1240         IF Tp[I]>=Conv[J] THEN Lcon[J] = Lcon[J]+Mcell
1250       NEXT J
1260     NEXT I
1270     FOR K = 1 TO 9
1280       IF Lcmax[K]>=Lcon[K] THEN 1500
1290       Lcmax[K] = Lcon[K]
1300       Xdel[K] = Dly
```

```
1500     NEXT K
1506     IF Ntank1=1 THEN EXIT TO 1520
1510   NEXT Jr
1520   IF Lalt=Ialt THEN 1900
1530   IF Jfirst=0 THEN 1800
1540   REM PRINT
1800   Jfirst = 1
1810   MOVE 0,95-Xpace*10 | SET TEXT COLOR 13
1811   TEXT USING "D,A,2D,9(4D)":Ialt,"x",Ntank1,Lcmax
1812   MOVE 0,90-Xpace*10 | SET TEXT COLOR 3 | TEXT USING "4X,9(X,D.D)":Xdel
1820   Lalt = Ialt
1830   GOTO 1950
1900   MOVE 0,95-Xpace*10 | SET TEXT COLOR 13
1901   TEXT USING "2X,2D,9(4D)":Ntank1,Lcmax
1902   MOVE 0,90-Xpace*10 | SET TEXT COLOR 3 | TEXT USING "4X,9(X,D.D)":Xdel
1950   Xpace = Xpace+1
2000 NEXT Jj
2010 REM END OOF LTHIS ALTITUDE AND VELOCITY
4999 END
5000 SELECT CASE K
5010 CASE 1:4:5:8:9:12:13:16
5020   GOTO 6000
5030 CASE ELSE
5040   GOTO 7000
5050 END SELECT
6000 Nintvx = Nintv1
6010 Lspx = Lsp1
6020 Singx = Sing1
6030 SET DIALOG COLOR 14 | PRINT "#1 JJ=";Jj | SET DIALOG COLOR 3
6040 RETURN
7000 Nintvx = Nintv2
7010 Lspx = Lsp2
7020 Singx = Sing2
7030 SET DIALOG COLOR 4 | PRINT "#2 jj=";Jj | SET DIALOG COLOR 3
7040 RETURN
```

LLDELAY.TAB

This program stores prints and stores the data for the detailed line length/opening delay tables, located near the end of the guideline.

```
  1 GOTO 3000
  4 GOTO 100
  8 GOTO 700
 12 GOTO 4000
 16 GOTO 800
 20 GOTO 1000
 24 GOTO 5000
 28 GOTO 6000
100 CLEAR
110 DIM D1[50,8],D2[50,8],Z1[50],Z2[50]
120 D1 = 0
130 D3 = 0
140 D2 = 0
150 D4 = 0
160 DATA 0.5,1,2,3,4,6,8,10
170 DIM Z[8]
```

```
180 RESTORE 160
190 FOR I = 1 TO 8
200   READ Z[I]
210 NEXT I
220 DATA 1.1,1.2,1.3,1.6,1.1
230 DATA 1.2,1.3,1.6,1.1,1.2
240 DATA 1.3,1.6,1.1,1.2,1.3
250 DATA 1.6,1.1,1.2,1.3,1.6
260 DATA 2.1,2.2,2.3,2.1,2.2,2.3,2.1,2.2,2.3,2.1
270 DATA 2.2,2.3,2.1,2.2,2.3,3.1,3.2,3.1,3.2,3.1
280 DATA 3.2,3.1,3.2,3.1,3.2,6.1,6.1,6.1,6.1,6.1
310 RESTORE 220
320 FOR I = 1 TO 50
330   READ Z1[I]
340 NEXT I
350 DATA 1,1,1,1,2,2,2,2,3,3,3,3,4,4,4,4,5,5,5,5,1,1,1
360 DATA 2,2,2,3,3,3,4,4,4,5,5,5,1,1,2,2,3,3,4,4
370 DATA 5,5,1,2,3,4,5
380 RESTORE 350
390 FOR I = 1 TO 50
400   READ V3
410   Z2[I] = V3*100
420 NEXT I
440 FOR I = 1 TO 8
450   FOR J = 1 TO 50
460     PRINT Z1[J];"  ";Z[I];" gpc ";Z2[J];" feet ";
470     INPUT D1[J,I]
480   NEXT J
490 NEXT I
500 PRINT "DELAYS"
510 FOR I = 1 TO 8
520   FOR J = 1 TO 50
530     PRINT Z1[J];"  ";Z[I];" gpc ";Z2[J];" FEET ";
540     INPUT D2[J,I]
550   NEXT J
560 NEXT I
570 PRINT "DATA ENTERED"
580 PRINT "DO YOU WANT TO STORE THE DATA ON A FILE? ";
590 INPUT Z$
600 O$ = SEG$(Z$,1,1)
610 IF O$="Y" THEN 700
620 END
700 PRINT "ENTER TITLE-";
710 INPUT Q$
720 PRINT "WHAT FILE? ";
730 INPUT F$
740 OPEN #1:F$,"F"
750 PRINT #1:F$,Q$,D1,D2
760 PRINT "DATA FOR: ";Q$;" ON HARD DISC ON FILE ";F$
770 CLOSE
780 END
800 PRINT "WHAT FILE? ";
810 INPUT F$
811 DELETE D1,D2,Z1,D3,D4,Z2
812 DIM D1[50,8],D2[50,8]
820 OPEN #1:F$,"R"
830 INPUT #1:F$,Q$,D1,D2
```

```
 840 PRINT "DATA ENTERED FROM FILE ";F$;" ";Q$
 850 END
1000 OPEN #41:"printfile","f"
1010 PRINT #41:Q$
1020 Z4 = 0
1030 C = 1
1040 S$ = "                          |------------|------------|------"
1050 T$ = "------|------------|------------|------------|------------|"
1060 DATA 1,2,3,6,1,2,3,6,1,2,3,6,1,2,3,6,1,2,3,6
1065 DATA 1,2,3,1,2,3,1,2,3,1,2,3,1,2,3
1070 DATA 1,2,1,2,1,2,1,2,1,2,1,1,1,1,1
1090 P$ = "------------|"
1100 RESTORE 1060
1110 DELETE Z3
1120 DIM Z3[50]
1130 FOR I = 1 TO 50
1140   READ Z3[I]
1150 NEXT I
1160 PRINT #41:"                           ";
1170 FOR I = 26 TO 129
1180   PRINT #41:"_";
1190 NEXT I
1200 PRINT #41:"_"
1210 PRINT #41:"                          |";
1220 PRINT #41:"         LEVEL 1          |";
1230 PRINT #41:"   LEVEL 2   |   LEVEL 3  |                LEVEL 4";
1240 PRINT #41:"                          |"
1250 PRINT #41:S$;T$;P$
1260 PRINT #41:"                          |";
1270 PRINT #41:"                                   COVERAGE(GALLONS/";
1280 PRINT #41:"100 SQ.FT.)                        |"
1290 PRINT #41:S$;T$;P$
1300 PRINT #41:"                          |";
1310 PRINT #41 USING 2790:0.5,"|",1,"|",2,"|",3,"|",4,"|",6,"|",8,"|"
1320 PRINT #41:"   10.0     |"
1330 S$ = "|------------|----|--------|------------|------------|------"
1340 PRINT #41:S$;T$;P$
1350 PRINT #41:"|COMPARTMENTS|DROP|NO.OF    |  MAX  |DELAY|  MAX  |DELAY|";
1360 PRINT #41:"  MAX  |DELAY|  MAX  |DELAY|  MAX  |DELAY|  MAX  |DELAY|";
1370 PRINT #41:"  MAX  |DELAY|  MAX  |DELAY|"
1380 PRINT #41:"|  RELEASED  | HT |PATTERNS|LENGTH|(SEC)|LENGTH|(SEC)|";
1390 PRINT #41:"LENGTH|(SEC)|LENGTH|(SEC)|LENGTH|(SEC)|LENGTH|(SEC)|";
1400 PRINT #41:"LENGTH|(SEC)|LENGTH|(SEC)|"
1410 PRINT #41:"|  AT A TIME | FT |        | (FT) |     | (FT) |     |";
1420 PRINT #41:" (FT) |     | (FT) |     | (FT) |     | (FT) |     |";
1430 PRINT #41:" (FT) |     | (FT) |     |"
1440 S$ = "|--  ---  ---|----|--------|------|-----|------|-----|------|"
1450 T$ = "-----|------|-----|------|-----|------|-----|------|-----|"
1460 P$ = "------|-----|"
1470 DELETE V$,U$
1480 DIM V$(132),U$(132)
1490 U$ = S$ & T$
1500 U$ = U$ & P$
1510 PRINT #41:U$
1520 S$ = "|            |----|--------|------|-----|------|-----|------|"
1530 V$ = S$ & T$
```

```
1540 V$ = V$ & P$
1550 FOR I = 1 TO 50
1560   IF I=3 OR I=27 OR I=47 OR I=61 OR I=71 THEN 2380
1570   IF I=8 OR I=31 OR I=49 OR I=63 OR I=72 THEN 2400
1580   IF I=13 THEN 2440
1590   IF I=35 THEN 2460
1600   IF I=53 THEN 2480
1610   IF I=65 THEN 2500
1615   IF I=73 THEN 2520
1620   IF I=18 OR I=39 OR I=56 OR I=67 OR I=74 THEN 2640
1630   IF I=23 OR I=43 OR I=59 OR I=69 OR I=75 THEN 2760
2070   IF Z3[I]<>12 THEN 2075
2071   PRINT #41:"|             |    |   ";Z3[I];"   ";
2072   GOTO 2080
2075   PRINT #41:"|             |    |    ";Z3[I];"   ";
2080   FOR J = 1 TO 8
2081     IF Q$<>"BLANK" THEN 2090
2082     IF D1[I,J]=0 THEN 2095
2090     PRINT #41 USING "A,6D,A,3D.D,S":"|",D1[I,J],"|",D2[I,J]
2093     GOTO 2100
2095     PRINT #41 USING "A,6X,A,5X,S":"|","|"
2100   NEXT J
2110   PRINT #41:"|"
2115   REM NEXT IS LONG LINE
2120   IF I=25 OR I=45 OR I=60 OR I=70 OR I=75 THEN 2830
2125   REM NEXT TWO ARE SHORT LINES
2130   IF I=5 OR I=10 OR I=15 OR I=20 OR I=29 OR I=33 OR I=37 THEN 2810
2140   IF I=41 OR I=48 OR I=51 OR I=54 OR I=57 OR I=62 THEN 2810
2141   IF I=64 OR I=66 OR I=68 THEN 2810
2340 NEXT I
2350 Z4 = 1
2360 CALL "lpr printfile"
2361 END
2370 NEXT I
2380 PRINT #41:"|            | 100|    ";Z3[I];"   ";
2390 GOTO 2080
2400 PRINT #41:"|            | 200|    ";Z3[I];"   ";
2410 GOTO 2080
2420 ON C GOTO 2440,2460,2480,2500,2520,2540,2560,2580,2580,2580
2440 PRINT #41:"|     ONE    | 300|    ";Z3[I];"   ";
2450 GOTO 2590
2460 PRINT #41:"|     TWO    | 300|    ";Z3[I];"   ";
2470 GOTO 2590
2480 PRINT #41:"|    FOUR    | 300|    ";Z3[I];"   ";
2490 GOTO 2590
2500 PRINT #41:"|     SIX    | 300|    ";Z3[I];"   ";
2510 GOTO 2590
2520 PRINT #41:"|   TWELVE   | 300|    ";Z3[I];"   ";
2530 GOTO 2590
2580 GOTO 2860
2590 C = C+1
2600 GOTO 2080
2610 ON C-1 GOTO 2640,2660,2680,2700,2620,2720,2740,2620,2620,2620
2620 PRINT #41:"| (ALL COMB) | 400|    ";Z3[I];"   ";
2630 GOTO 2080
2640 PRINT #41:"|            | 400|    ";Z3[I];"   ";
2650 GOTO 2080
```

```
2660 PRINT #41:"|     (I)     | 400|    ";Z3[I];"   ":
2670 GOTO 2080
2680 PRINT #41:"|    (O,I)    | 400|    ";Z3[I];"   ":
2690 GOTO 2080
2700 PRINT #41:"|    (I,I)    | 400|    ";Z3[I];"   ":
2710 GOTO 2080
2720 PRINT #41:"|    (O+I)    | 400|    ";Z3[I];"   ":
2730 GOTO 2080
2740 PRINT #41:"|    (I+I)    | 400|    ";Z3[I];"   ":
2750 GOTO 2080
2760 PRINT #41:"|             | 500|    ";Z3[I];"   ":
2770 GOTO 2080
2780 CALL "lpr printfile"
2781 END
2790 IMAGE 7(4X,2D.D,4X,A),S
2800 IMAGE A,5D,A,D.D,S
2810 PRINT #41:V$
2820 GOTO 2340
2830 PRINT #41:U$
2840 IF Z4=1 THEN 2360
2850 GOTO 2340
2860 ON C-7 GOTO 2880,2900,2920
2870 GOTO 2590
2880 PRINT #41:"|     TWO     | 300|    ";Z3[I];"   ":
2890 GOTO 2590
2900 PRINT #41:"|   THREE     | 300|    ";Z3[I];"   ":
2910 GOTO 2590
2920 PRINT #41:"|   SIX       | 300|    ";Z3[I];"   ":
2930 GOTO 2590
3000 CLEAR
3010 PRINT "USER DEFINABLE KEYS:"
3020 PRINT "1.  ENTER DATA"
3030 PRINT "2.  STORE DATA"
3040 PRINT "3.  MAKE CORRECTION"
3050 PRINT "4.  RETRIVE DATA"
3060 PRINT "5.  PRINT LINE LENGTH-DELAY TABLE"
3065 PRINT "6.  SUBTRACT WATER FROM RETARDANT & PRINT TABLE"
3066 PRINT "7.  PRINT TABLE W/O LINES (FOR PRINTERS)"
3080 END
3090 FOR I = 1 TO 30
3100   FOR J = 1 TO 8
3110     D1[I,J] = 100*I+J
3120     D2[I,J] = 1+J/10
3130   NEXT J
3140 NEXT I
3150 GOTO 570
3160 END
4000 CLEAR
4010 PRINT "ENTER THE ROW NUMBER THEN THE GPC ";
4020 INPUT C1,C2
4021 IF C1=0 AND C2=0 THEN 580
4030 IF C2=6 THEN 4070
4040 IF C2<>8 THEN 4050
4042 C2 = 7
4044 GOTO 4070
4050 IF C2<>10 THEN 4060
4052 C2 = 8
```

```
4054 GOTO 4070
4060 C2 = INT(C2+1)
4070 PRINT "THE PRESENT VALUES ARE : ";D1[C1,C2];" ";D2[C1,C2]
4080 PRINT "ENTER NEW VALUES ";
4090 INPUT D1[C1,C2],D2[C1,C2]
4095 GOTO 4010
5000 CLEAR
5005 DELETE W1,R1,D1,D2
5010 DIM W1[50,8],R1[50,8],D2[50,8],D1[50,8]
5020 PRINT "WHAT FILE FOR WATER? ";
5030 INPUT F$
5040 OPEN #1:F$,"R"
5050 READ #1:F$,W$,W1
5060 PRINT "WHAT FILE FOR RETARDANT? ";
5070 INPUT G$
5080 OPEN #2:G$,"R"
5090 READ #2:G$,R$,R1
5100 D1 = R1-W1
5110 D2 = 0
5120 Q$ = "RETARDANT-WATER"
5125 CLOSE
5130 GOTO 1000
6000 REM
6010 OPEN #41:"PRINTFILE","W"
6020 PRINT #41:
6030 Z4 = 0
6040 C = 1
6050 S$ = ""
6060 T$ = ""
6070 DATA 1,2,3,6,1,2,3,6,1,2,3,6,1,2,3,6,1,2,3,6,1,2,3,1,2,3,1,2,3
6080 DATA 1,2,3,1,2,3,1,2,1,2,1,2,1.2,1,2,1,1,1,1,1
6100 P$ = ""
6110 RESTORE 6070
6120 DELETE Z3
6130 DIM Z3[50]
6140 FOR I = 1 TO 50
6150   READ Z3[I]
6160 NEXT I
6170 PRINT #41:
6210 PRINT #41:
6220 PRINT #41:"                             ";
6230 PRINT #41:"         LEVEL 1          ";
6240 PRINT #41:"   LEVEL 2      LEVEL 3                  LEVEL 4";
6250 PRINT #41:"                             "
6260 PRINT #41:
6270 PRINT #41:"                            ";
6280 PRINT #41:"                                    COVERAGE(GALLONS/";
6290 PRINT #41:"100 SQ.FT.)                                      "
6300 PRINT #41:
6310 PRINT #41:"                            ";
6320 PRINT #41 USING 7800:0.5," ",1," ",2," ",3," ",4," ",6," ",8," "
6330 PRINT #41:"   10.0      "
6350 PRINT #41:
6360 PRINT #41:" COMPARTMENTS DROP NO.OF     MAX  DELAY   MAX  DELAY ";
```

```
6370 PRINT #41:"  MAX  DELAY   MAX  DELAY   MAX  DELAY   MAX  DELAY ";
6380 PRINT #41:"  MAX  DELAY   MAX  DELAY "
6390 PRINT #41:"   RELEASED    HT  PATTERNS LENGTH (SEC) LENGTH (SEC) ";
6400 PRINT #41:"LENGTH (SEC) LENGTH (SEC) LENGTH (SEC) LENGTH (SEC) ";
6410 PRINT #41:"LENGTH (SEC) LENGTH (SEC) "
6420 PRINT #41:"   AT A TIME   FT            (FT)         (FT)         ";
6430 PRINT #41:" (FT)         (FT)         (FT)         (FT)         ";
6440 PRINT #41:" (FT)         (FT)         "
6500 U$ = ""
6520 PRINT #41:
6540 V$ = ""
6560 FOR I = 1 TO 50
6562   IF I=3 OR I=36 OR I=46 OR I=22 THEN 6800
6570   IF I=6 OR I=25 OR I=38 OR I=47 THEN 6820
6580   IF I=10 THEN 6850
6590   IF I=28 THEN 6870
6600   IF I=40 THEN 6890
6610   IF I=48 THEN 6910
6620   IF I=14 OR I=31 OR I=42 OR I=49 THEN 6990
6630   IF I=18 OR I=34 OR I=44 OR I=50 THEN 7110
6640   PRINT #41:"                       ";Z3[I];"   ";
6650   FOR J = 1 TO 8
6660     IF Q$<>"BLANK" THEN 6680
6670     IF D1[I,J]=0 THEN 6700
6680     PRINT #41 USING "A,6D,A,3D.D,S":" ",D1[I,J]," ",D2[I,J]
6690     GOTO 6710
6700     PRINT #41 USING "A,6X,A,5X,S":" "," "
6710   NEXT J
6720   PRINT #41:" "
6730   IF I=20 OR I=35 OR I=45 OR I=50 THEN 7180
6740   IF I=4 OR I=8 OR I=12 OR I=16 OR I=23 OR I=26 OR I=29 THEN 7160
6750   IF I=32 OR I=37 OR I=39 OR I=41 OR I=43 THEN 7160
6760 NEXT I
6770 Z4 = 1
6780 END
6790 NEXT I
6800 PRINT #41:"               100     ";Z3[I];"   ";
6810 GOTO 6650
6820 PRINT #41:"               200     ";Z3[I];"   ";
6830 GOTO 6650
6840 ON C GOTO 6850,6870,6890,6910,2520,2540,2560,6930,6930,6930
6850 PRINT #41:"      ONE      300     ";Z3[I];"   ";
6860 GOTO 6940
6870 PRINT #41:"      TWO      300     ";Z3[I];"   ";
6880 GOTO 6940
6890 PRINT #41."     THREE     300     ";Z3[I];"   ";
6900 GOTO 6940
6910 PRINT #41:"|     SIX      300     ";Z3[I];"   ";
6920 GOTO 6940
6930 GOTO 7210
6940 C = C+1
6950 GOTO 6650
6960 ON C-1 GOTO 6990,7010,7030,7050,6970,7070,7090,6970,6970,6970
6990 PRINT #41:"               400     ";Z3[I];"   ";
7000 GOTO 6650
7110 PRINT #41:"               500     ";Z3[I];"   ";
7120 GOTO 6650
```

```
7130 CALL "lpr PRINTFILE"
7131 END
7140 IMAGE 7(4X,2D.D,4X,A),S
7150 IMAGE A,5D,A,D.D,S
7160 PRINT #41:V$
7170 GOTO 6760
7180 PRINT #41:U$
7190 IF Z4=1 THEN 6780
7200 GOTO 6760
7210 ON C-7 GOTO 7230,7250,7270
7220 GOTO 6940
7230 PRINT #41:"|     TWO     | 300|     ";Z3[I];"    ";
7240 GOTO 6940
7250 PRINT #41:"|    THREE    | 300|     ";Z3[I];"    ";
7260 GOTO 6940
7270 PRINT #41:"|    SIX      | 300|     ";Z3[I];"    ";
7280 GOTO 6940
7800 IMAGE 7(4X,2D.D,4X,A),S
```

LDRWIDTH

This program requires input of data from the detailed pattern section of the PATSIM output and calculates the line length, downrange position and width for 1, 2, 3, 4, and 5 gpc to be used in the FOOTPRINTS. Because the detailed pattern section of the PATSIM output is bilaterally symetrical about rows 14-15, only data from the left side are entered. The program uses a linear interpolation for its calculations and starts at 1 gpc. Data more than one space to the left or above and below 1-gpc values are not used and need not be entered.

```
  8 GOTO 50000
 20 GOTO 50000
100 REM CALCULATE THE AVERAGE WIDTH, DOWNRANGE AND LENGHT FROM PATSIM
105 K7 = 0
110 PRINT "ENTER THE ID FOR THIS DROP--";
120 INPUT I$
130 DIM D[40,14],Ans[40,5],Start[2],Finish[2]
140 Ans = 0
150 D = 0
160 Start = 0
170 Finish = 0
180 PRINT "DO YOU WISH TO RECALL A FILE? IF YES ENTER NAME ELSE CR ";
190 INPUT F$
200 IF F$="" THEN 250
205 DIM X$(300)
210 OPEN #1:F$,"R",X$
220 READ #1:I$,D
230 GOTO 490
240 PRINT "ENTER -1 TO TERMINATE A COLUMN"
250 FOR I = 1 TO 7
260   FOR J = 1 TO 40
270     PRINT "WHAT IS THE VALUE No.";J;" FOR COL. ";I+7;" ? ";
280     INPUT Test
290     IF Test<0 THEN EXIT TO 320
300     D[J,I] = Test
310   NEXT J
320 NEXT I
330 FOR I = 1 TO 40
340   D[I,8] = D[I,7]
350   D[I,9] = D[I,6]
```

```
360   D[I,10] = D[I,5]
370   D[I,11] = D[I,4]
380   D[I,12] = D[I,3]
390   D[I,13] = D[I,2]
400   D[I,14] = D[I,1]
410 NEXT I
420 PRINT "WHAT FILE FOR STORAGE? ";
430 INPUT S$
450 OPEN #1:S$,"F",X$
460 WRITE #1:I$,D
470 CLOSE
480 PRINT "DATA SAVED ON DISC FILE ";S$
490 Count = 1
500 Start = 0
520 FOR Gpc = 1 TO 5
530   FOR Row = 1 TO 14
540     IF Start[1]>0 THEN 590
550     IF D[Count,Row]<Gpc THEN 630
560     IF Start[1]<>0 THEN 630
570     Start[1] = Row
580     Start[2] = D[Count,Row]
590     IF D[Count,Row]>=Gpc THEN 630
600     Finish[1] = Row-1
610     Finish[2] = D[Count,Finish[1]]
620     EXIT TO 640
630   NEXT Row
640   IF Start[1]=0 THEN 790
650   W = (Finish[1]-Start[1])*15
660   IF Start[1]=1 THEN 710
670   Wtop = (Start[2]-Gpc)/(Start[2]-D[Count,Start[1]-1])*15
680   Wbot = (Finish[2]-Gpc)/(Finish[2]-D[Count,Finish[1]+1])*15
690   W = W+Wtop+Wbot
700   GOTO 740
710   Wtop = (Start[2]-Gpc)/Start[2]*15
720   Wbot = (Finish[2]-Gpc)/Finish[2]*15
730   W = W+Wtop+Wbot
740   Ans[Count,Gpc] = W
750   REM print "*";gpc;" ";w;" ";Start(1);" ";finish(1);"*";wtop;" ";wbot
760   Start = 0
770   Row = 0
780 NEXT Gpc
790 Count = Count+1
800 IF Count=41 THEN 820
810 GOTO 520
820 DIM Som[5]
830 Som = 0
840 FOR Gpc = 1 TO 5
850   FOR I = 1 TO 40
860     Som[Gpc] = Som[Gpc]+Ans[I,Gpc]
870   NEXT I
880 NEXT Gpc
890 CLEAR
1000 DIM Ave[5]
1010 De = 41
1020 Ave = 0
1030 Count1 = 0
1040 Count2 = 0
```

```
 1050 Count3 = 0
 1060 Count4 = 0
 1070 Count5 = 0
 1080 P$ = "5(1X,4D.D,2X)"
 1090 FOR I = 1 TO 40
 1100   IF Ans[I,1]=0 THEN 1200
 1110   Count1 = Count1+1
 1120   IF Ans[I,2]=0 THEN 1200
 1130   Count2 = Count2+1
 1140   IF Ans[I,3]=0 THEN 1200
 1150   Count3 = Count3+1
 1160   IF Ans[I,4]=0 THEN 1200
 1170   Count4 = Count4+1
 1180   IF Ans[I,5]=0 THEN 1200
 1190   Count5 = Count5+1
 1200 NEXT I
 1210 Ave[1] = Som[1]/Count1
 1220 IF Som[2]=0 THEN 1380
 1230 Ave[2] = Som[2]/Count2
 1240 IF Som[3]=0 THEN 1380
 1250 Ave[3] = Som[3]/Count3
 1260 IF Som[4]=0 THEN 1380
 1270 Ave[4] = Som[4]/Count4
 1280 IF Som[5]=0 THEN 1380
 1290 Ave[5] = Som[5]/Count5
 1380 GOTO 10000
10000 DIM D14[40],L[5,8],L9[5],M2[8]
10010 D14 = 0
10020 FOR I = 1 TO 40
10030   D14[I] = D[I,7]
10040 NEXT I
10050 L = 0
10060 L9 = 0
10070 M2 = 0
10080 FOR J = 1 TO 5
10090   C = 1
10100   K = 1
10110   IF D14[K]>=J THEN 10150
10120   K = K+1
10130   IF K=41 THEN 10370
10140   GOTO 10110
10150   A = K*30
10160   O = D14[K]
10170   IF K<>1 THEN 10200
10180   U = 0
10190   GOTO 10210
10200   U = D14[K-1]
10210   A = A-30/(O-U)*(O-J)
10220   L[J,C] = A
10230   C = C+1
10240   K = K+1
10250   IF K=41 THEN 10310
10260   IF D14[K]<J THEN 10300
10270   K = K+1
10280   IF K=41 THEN 10370
10290   GOTO 10260
```

```
10300   B = (K-1)*30
10310   O = D14[K-1]
10320   U = D14[K]
10330   B = B+30/(O-U)*(O-J)
10340   L[J,C] = B
10350   C = C+1
10360   GOTO 10120
10370   L9[J] = L9[J]+(L[J,2]-L[J,1])+(L[J,4]-L[J,3])+(L[J,6]-L[J,5])
10380   L9[J] = L9[J]+L[J,8]-L[J,7]
10390 NEXT J
20000 REM PRINT SECTION
20001 Far = LEN(X$)
20002 X$ = SEG$(X$,200,Far-200)
20003 X$ = EDIT$(X$,"b")
20020 P$ = "2X,2(4D,X),S"
20022 DELETE FILE "printfile"
20025 OPEN #2:"printfile","f"
20030 PRINT #2:I$;"  ";X$
20031 PRINT #2:
20032 PRINT #2:
20040 PRINT #2:"********************************************************";
20050 PRINT #2:"************"
20060 PRINT #2:"   ";"     ";
20070 PRINT #2:"    1           2           3           4           5"
20080 PRINT #2:"*********DR***D+L****DR***D+L****DR***D+L****DR***D+L***";
20090 PRINT #2:"*DR***D+L**"
20100 R$ = "4X,4D,4X,S"
20110 FOR J = 1 TO 5
20120   ON J GOTO 20130,20270,20400,20530,20660
20130   PRINT #2:"L1   ";
20140   FOR I1 = 1 TO 5
20150     PRINT #2 USING P$:L[I1,1],L[I1,2]
20160   NEXT I1
20170   PRINT #2:
20180   PRINT #2:"LEN  ";
20190   FOR Count = 1 TO 5
20200     PRINT #2 USING R$:L[Count,2]-L[Count,1]
20210   NEXT Count
20220   PRINT #2:
20230   PRINT #2:"---------------------------------------------------------";
20240   PRINT #2:"----------"
20250 NEXT J
20260 GOTO 20660
20270 PRINT #2:"L2   ";
20280 FOR I1 = 1 TO 5
20290   PRINT #2 USING P$:L[I1,3],L[I1,4]
20300 NEXT I1
20310 PRINT #2:
20320 PRINT #2:"LEN  ";
20330 FOR Count = 1 TO 5
20340   PRINT #2 USING R$:L[Count,4]-L[Count,3]
20350 NEXT Count
20360 PRINT #2:
20370 PRINT #2:"---------------------------------------------------------";
20380 PRINT #2:"----------"
20390 GOTO 20250
20400 PRINT #2:"L3   ";
```

```
20410 FOR I1 = 1 TO 5
20420   PRINT #2 USING P$:L[I1,5],L[I1,6]
20430 NEXT I1
20440 PRINT #2:
20450 PRINT #2:"LEN  ";
20460 FOR Count = 1 TO 5
20470   PRINT #2 USING R$:L[Count,6]-L[Count,5]
20480 NEXT Count
20490 PRINT #2:
20500 PRINT #2:"-------------------------------------------------------";
20510 PRINT #2:"----------"
20520 GOTO 20250
20530 PRINT #2:"L4   ";
20540 FOR I1 = 1 TO 5
20550   PRINT #2 USING P$:L[I1,7],L[I1,8]
20560 NEXT I1
20570 PRINT #2:
20580 PRINT #2:"LEN  ";
20590 FOR Count = 1 TO 5
20600   PRINT #2 USING R$:L[Count,8]-L[Count,7]
20610 NEXT Count
20620 PRINT #2:
20630 PRINT #2:"-------------------------------------------------------";
20640 PRINT #2:"----------"
20650 GOTO 20250
20660 Q$ = "4X,3D.D,3X,S"
20670 PRINT #2:"WIDTH ";
20680 FOR I = 1 TO 5
20690   PRINT #2 USING Q$:Ave[I]
20700 NEXT I
20710 PRINT #2:
30000 PRINT #2:"ROW     8     9    10    11    12    13    14"
30010 FOR I = 1 TO 22
30020   PRINT #2 USING "2D,3X,S":I
30030   FOR J = 1 TO 7
30040     PRINT #2 USING "X,2D.D,X,S":D[I,J]
30050   NEXT J
30060   PRINT #2:
30070 NEXT I
30080 CLOSE #2
30085 CALL "lpr printfile"
30090 GOTO 100
50000 REM correct data
50005 K7 = 1
50010 PRINT "WHAT FILE? ";
50020 INPUT F$
50030 DIM D[40,14],Ans[40,5],Start[2],Finish[2]
50031 Ans = 0
50032 Start = 0
50033 D = 0
50034 Finish = 0
50040 OPEN #1:F$,"R",X$
50050 READ #1:I$,D
50055 CLOSE
50060 CLEAR
50070 PRINT "DATE FOR: ";I$;" IN MEMORY"
50071 PRINT "ENTER P FOR PRINT ELSE CR";
```

```
50072 INPUT Q$
50073 IF Q$="P" THEN 490
50080 PRINT "TO EXIT CORRECTION FOR THIS FILE ENTER -1 FOR COLUMN AND ROW"
50090 PRINT "ENTER COLUMN THEN ROW ";
50100 INPUT Column,Row
50105 Column = Column-7
50110 IF Column<0 THEN 50150
50120 PRINT "PRESENT VALUE: ";D[Row,Column];" NEW VALUE? ";
50130 INPUT D[Row,Column]
50140 GOTO 50090
50150 REM STORAGE AND FILLOUT SECTION
50160 FOR I = 1 TO 40
50170   D[I,8] = D[I,7]
50180   D[I,9] = D[I,6]
50190   D[I,10] = D[I,5]
50200   D[I,11] = D[I,4]
50210   D[I,12] = D[I,3]
50220   D[I,13] = D[I,2]
50230   D[I,14] = D[I,1]
50240 NEXT I
50250 PRINT "PRESS RETURN TO RESTORE DATA ON THE SAME FILE ";
50260 INPUT Q$
50270 OPEN #1:F$,"F",X$ ! ??
50280 WRITE #1:I$,D
50290 CLOSE
50300 PRINT "DO YOU WANT TO PRINT THE NEW DATA? (Y OR N ) ";
50310 INPUT Q$
50320 IF Q$="N" THEN 50340
50330 GOTO 490
50340 END
```

BESTSTRAT.DAT/BS Plot

The line length versus height data for each drop type is smoothed by using a standard simple regression that determines the best fit of the data to one of eight curve forms, $Y = AX$; $Y = A+BX$; $Y = Ae^{BX}$; $Y = 1/(A+BX)$; $Y = A+B/X$; $Y = A+B\log X$; $Y = AX^B$; and $Y = X/(A+BX)$. Y = drop height and X = line length. These equations along with the type of drop are entered into BESTSTRAT.DAT lines 1000 to 2000 and the data are plotted. After selection of the type of drop for each volume, the remaining equations are set to 0 (lines 1000-2000) and a final plot made.

```
1 GO TO 100   !PRINT MENU
2 REM WATER LIKE 3 GPC CONAIR DC-6B TANKER 454
4 GO TO 2010   !CALCULATE STRATIGIES AND PLOT
8 GO TO 3270   !REPLOT WITH PREVIOUSLY ENTERED PARAMETERS
12 GO TO 8000   !PRINT A LABEL ON THE 4662 PLOTTER
16 T9=0   !PLOT CALCULATED DATA
17 GO TO 2010
20 GO TO 9000   !PRINT ON PLOTTER XTxXR LABEL
24 GO TO 11000   !DRAW LEFT ARROWHEAD
28 GO TO 10000   !DRAW RIGHT ARROWHEAD
44 APPEND "BSPLOT.A" AT 2000   !APPEND PLOT PROGRAM
45 V6=0
46 GO TO 4
100 CLEAR
102 V6=0
110 PRINT "1. CALCULATE DATA"
120 PRINT "2. DRAW AXES WITH PREVIOUSLY ENTERED PARAMETERS"
130 PRINT "3. ENTER AND PRINT A LABEL"
140 PRINT "4. INPUT PARAMETERS FOR AND DRAW GRAPH FROM CALCULATED DATA"
```

```
150 PRINT "5. PRINT XTxXR LABEL"
160 PRINT "6. DRAW LEFT POINT ARROWHEAD"
170 PRINT "7. DRAW RIGHT POINT ARROWHEAD"
180 PRINT "11. APPEND PLOT PORTION FRON 4907 DISC"
280 END
990 !PROGRAM EQUATIONS AND ID STRINGS FOR STRATIGIES X=0 FOR NO ENTRY
1000 A$="1X1 "
1010 X=0
1020 RETURN
1030 B$="1X2      "
1040 X=0
1050 RETURN
1060 C$="1X4"
1070 X=3614.14759953*J^-0.599571655413
1080 RETURN
1090 D$="1X12"  !EQUATION AT 1110 IS BASIS FOR NO CAPABILITY AREA
1095 IF J>376 THEN 1251
1100 X=1496.07186437*EXP(-0.00347487486045*J)
1110 RETURN
1120 E$="1X6"
1130 X=1295.28917901-189.349621044*LOG(J)
1140 RETURN
1150 F$="2X1"
1160 X=0
1170 RETURN
1180 G$="2X2"
1190 REM X=779.924741195-119.17387092*LOG(J)
1191 X=0
1200 RETURN
1210 H$="2X3"
1220 REM X=12637.4777927*J^-0.741958999899
1221 X=0
1230 RETURN
1240 I$="2X6"
1250 RETURN
1251 X=1/(5.69473125E-4+5.052039738E-6*J)
1260 RETURN
1270 J$="4X1"
1280 REM X=236.666666667-0.675*J
1281 X=0
1290 RETURN
1300 K$="4X2"
1310 REM X=587.447659418*EXP(-0.00286385476043*J)
1311 X=0
1320 RETURN
1330 L$="4X3"
1340 REM X=873.435667466*EXP(-0.00244759118039*J)
1341 X=0
1350 RETURN
1360 M$="6X1"
1370 REM X=864.121558318-135.493350465*LOG(J)
1371 X=0
1380 RETURN
1390 N$="6X2"
1400 REM X=751.760972274*EXP(-0.002435290718l*J)
1401 X=0
1410 RETURN
```

```
1420 O$="12X1"
1430 REM X=1762.81484802-292.712597148*LOG(J)
1431 X=0
1440 RETURN
2000 REM TARGET LINE FOR APPENDING PLOT PORTION
2000 REM PLOT PORTION OF BEST STRATEGY CHART
2010 DELETE A,B,C,D,E1,E2,E3,E4,E5,E6,E7,E8,E9,F1,F2
2020 DIM A(26),B(26),C(26),D(26),E1(26),E2(26),E3(26)
2030 DIM E4(26),E5(26),E6(26),E7(26),E8(26),E9(26)
2040 DIM F1(26),F2(26),Height(26)
2050 FOR I=1 TO 15
2060    C1=1
2070    FOR J=150 TO 500 STEP 14
2080       GOSUB I OF 1000,1030,1060,1090,1120,1150,1180,1210,1240,1270
2090       IF I<11 THEN 2110
2100       GOSUB I-10 OF 1300,1330,1360,1390,1420
2110       GOSUB I OF 2190,2220,2240,2260,2280,2300,2320,2340,2360,2380
2120       IF I<11 THEN 2140
2130       GOSUB I-10 OF 2400,2420,2440,2460,2480
2140       C1=C1+1
2150    NEXT J
2160 NEXT I
2170 T9=0
2180 GO TO 3000
2190 A(C1)=X
2200 Height(C1)=J
2210 RETURN
2220 B(C1)=X
2230 RETURN
2240 C(C1)=X
2250 RETURN
2260 D(C1)=X
2270 RETURN
2280 E1(C1)=X
2290 RETURN
2300 E2(C1)=X
2310 RETURN
2320 E3(C1)=X
2330 RETURN
2340 E4(C1)=X
2350 RETURN
2360 E5(C1)=X
2370 RETURN
2380 E6(C1)=X
2390 RETURN
2400 E7(C1)=X
2410 RETURN
2420 E8(C1)=X
2430 RETURN
2440 E9(C1)=X
2450 RETURN
2460 F1(C1)=X
2470 RETURN
2480 F2(C1)=X
2490 RETURN
3000 PRINT "ENTER MAXIMUM LINE LENGTH ";
3010 INPUT G
```

```
3020 IF G>0 THEN 3040
3030 STOP
3040 C5=0
3050 IF T9=0 THEN 3130  !REPLOT WITH SAME PARAMETERS
3060 IF G<=3000 THEN 3100
3070 WINDOW G-1500,G,0,500
3080 VIEWPORT 10,140,6,92.5
3090 GO TO 3160
3100 WINDOW G/2,G,0,500
3110 G2=G*(130/1500)/2
3120 GO TO 3150
3130 WINDOW 0,G,0,500
3140 G2=G*(130/1500)
3150 VIEWPORT 10,G2+10,6,92.5
3160 PRINT "DEVICE No. FOR PLOTTED OUTPUT? ";
3170 INPUT P
3180 IF T9>0 THEN 3270  !REPLOT WITH SAME PARAMETERS
3190 PRINT "ENTER 1 FOR LABELS ON BS LINES OR 0 FOR NO LABELS ";
3200 INPUT Q7
3210 PRINT "COVERAGE LEVEL? ";
3220 INPUT C2
3230 IF P<>1 THEN 3270  !IF NOT PLOTTER
3240 PRINT "SPEED? ";
3250 INPUT S
3260 PRINT @1,32:"BY";S
3270 PAGE
3280 PRINT @1,17:1.125,2.576
3290 MOVE @P:0,0
3300 DRAW @P:G,0
3310 DRAW @P:G,500
3320 DRAW @P:0,500
3330 DRAW @P:0,0
3340 MOVE @P:0,150
3350 DRAW @P:G,150
3360 FOR I=0 TO G STEP 100
3370    MOVE @P:I,0
3380    RMOVE @P:0,5
3390    RDRAW @P:0,-5
3400 NEXT I
3410 FOR I=0 TO G STEP 200
3420    MOVE @P:I+21,0
3430    PRINT @P:"J_H_H_H_";I
3440 NEXT I
3450 MOVE @P:G/2,0
3460 IF T9>0 THEN 3480
3470 PRINT @P:"J_J_J_H_H_H_H_H_H_H_H_H_H_H_H_DESIRED LINE LENGTH (FEET)";
3480 FOR I=100 TO 500 STEP 100
3490    MOVE @P:0,I
3500    RMOVE @P:10,0
3510    RDRAW @P:-10,0
3520    RMOVE @P:0,-5
3530    PRINT @P:"H_H_H_";I
3540 NEXT I
3550 IF P=32 THEN 3630
3560 MOVE @P:0,150
3570 PRINT @P:"H_H_H_H_H_";
3580 PRINT @1,25:90
```

```
3590 IF T9>0 THEN 3610
3600 PRINT @P:"DROP HEIGHT (FEET ABOVE GROUND)"
3610 PRINT @1,25:0
3620 IF T9>0 THEN 3880
3630 MOVE @P:G/2,70
3640 SET DEGREES
3650 PRINT @P:"H_H_H_H_H_H_H_H_H_H_AIRCRAFT SAFETY LIMIT"
3660 DIM Safex(10),Safey(10)  !DRAW SAFETY LIMIT
3670 Safex(1)=0
3680 Safex(2)=G
3690 Safex(3)=G
3700 Safex(6)=G/2-140
3710 Safex(4)=0
3720 Safex(5)=0
3730 Safex(7)=G/2+145
3740 Safex(8)=G/2+145
3750 Safex(9)=G/2-140
3760 Safex(10)=G/2-140
3770 Safey(1)=0
3780 Safey(7)=75+10
3790 Safey(2)=0
3800 Safey(3)=150
3810 Safey(4)=150
3820 Safey(5)=0
3830 Safey(6)=75-10
3840 Safey(7)=75-10
3850 Safey(8)=75+10
3860 Safey(9)=75+10
3870 Safey(10)=75-10
3880 HATCH ROTATE -45
3890 HATCH SPACE 4
3900 HATCH ALIGN 10,31.95
3910 HATCH @P:Safex,Safey
3920 MOVE @P:0,500
3930 IF T9>0 THEN 3950
3940 PRINT @P:"K_      COVERAGE LEVEL: ";C2
3950 IF V6=1 THEN 3980  !V6=1 IF HIT PROBABILITY FILE HAS BEEN READ
3960 GOSUB 7000
3970 CLOSE
3980 PRINT "ENTER 1 FOR LINE HP OR 0 FOR FULL HP";
3990 INPUT Q9
4000 IF Q9=1 THEN 4050
4010 HATCH ALIGN 10,31.95
4020 HATCH ROTATE 0
4030 HATCH SPACE 0.7
4040 HATCH @P:Hx,Hy
4050 MOVE @P:Hx(1),Hy(1)
4060 DRAW @P:Hx,Hy
5000 MOVE @P:A(1),Height(1)  !DRAW STRATEGY CURVES
5010 DRAW @P:A,Height
5020 IF Q7=0 THEN 5050
5030 MOVE @P:A(15),Height(15)
5040 PRINT @P:"H_";A$
5050 REM GO TO 19100
5060 MOVE @P:B(1),Height(1)
5070 DRAW @P:B,Height
5080 IF Q7=0 THEN 5110
```

```
5090 MOVE @P:B(14),Height(14)
5100 PRINT @P:"H_";B$
5110 REM GO TO 19100
5120 MOVE @P:C(1),Height(1)
5130 DRAW @P:C,Height
5140 IF Q7=0 THEN 5170
5150 MOVE @P:C(13),Height(13)
5160 PRINT @P:"H_";C$
5170 REM GO TO 19100
5180 MOVE @P:D(1),Height(1)
5190 DRAW @P:D,Height
5200 IF Q7=0 THEN 5230
5210 MOVE @P:D(12),Height(12)
5220 PRINT @P:"H_";D$
5230 REM GO TO 19100
5240 MOVE @P:E1(1),Height(1)
5250 DRAW @P:E1,Height
5260 IF Q7=0 THEN 5290
5270 MOVE @P:E1(11),Height(11)
5280 PRINT @P:"H_";E$
5290 REM GO TO 19100
5300 MOVE @P:E2(1),Height(1)
5310 DRAW @P:E2,Height
5320 IF Q7=0 THEN 5350
5330 MOVE @P:E2(10),Height(10)
5340 PRINT @P:"H_";F$
5350 REM GO TO 19100
5360 MOVE @P:E3(1),Height(1)
5370 DRAW @P:E3,Height
5380 IF Q7=0 THEN 5410
5390 MOVE @P:E3(9),Height(9)
5400 PRINT @P:"H_";G$
5410 REM GO TO 19100
5420 MOVE @P:E4(1),Height(1)
5430 DRAW @P:E4,Height
5440 IF Q7=0 THEN 5470
5450 MOVE @P:E4(8),Height(8)
5460 PRINT @P:"H_";H$
5470 REM GO TO 19100
5480 MOVE @P:E5(1),Height(1)
5490 DRAW @P:E5,Height
5500 IF Q7=0 THEN 5530
5510 MOVE @P:E5(7),Height(7)
5520 PRINT @P:"H_";I$
5530 REM GO TO 19100
5540 MOVE @P:E6(1),Height(1)
5550 DRAW @P:E6,Height
5560 IF Q7=0 THEN 5590
5570 MOVE @P:E6(6),Height(6)
5580 PRINT @P:"H_";J$
5590 REM GO TO 19100
5600 MOVE @P:E7(1),Height(1)
5610 DRAW @P:E7,Height
5620 IF Q7=0 THEN 5650
5630 MOVE @P:E7(5),Height(5)
5640 PRINT @P:"H_";K$
5650 MOVE @P:E8(1),Height(1)
```

```
5660 DRAW @P:E8,Height
5670 IF Q7=0 THEN 5700
5680 MOVE @P:E8(4),Height(4)
5690 PRINT @P:"H_";L$
5700 MOVE @P:E9(1),Height(1)
5710 DRAW @P:E9,Height
5720 IF Q7=0 THEN 5750
5730 MOVE @P:E9(8),Height(8)
5740 PRINT @P:"H_";M$
5750 MOVE @P:F1(1),Height(1)
5760 DRAW @P:F1,Height
5770 IF Q7=0 THEN 5800
5780 MOVE @P:F1(17),Height(17)
5790 PRINT @P:"H_";N$
5800 MOVE @P:F2(1),Height(1)
5810 DRAW @P:F2,Height
5820 IF Q7=0 THEN 6000
5830 MOVE @P:F2(16),Height(16)
5840 PRINT @P:"H_";O$
6000 DIM Capx(62),Capy(62)  !DRAW NO CAPABILITY SECTION
6010 Count=1
6020 FOR J=150 TO 700 STEP 10
6030    GOSUB 1090
6040    Capx(Count)=X
6050    Capy(Count)=J
6060    Count=Count+1
6070 NEXT J
6080 Capx(55)=G
6090 Capy(55)=500
6100 Capx(56)=G
6110 Capy(56)=150
6120 Capx(57)=Capx(1)
6130 Capy(57)=150
6140 Startx=(G+D(20))/2
6150 Starty=Height(20)
6160 Capx(58)=Startx
6170 Capy(58)=Starty
6180 Capx(59)=Startx+160
6190 Capy(59)=Starty
6200 Capx(60)=Startx+160
6210 Capy(60)=Starty+35
6220 Capx(61)=Startx
6230 Capy(61)=Starty+35
6240 Capx(62)=Startx
6250 Capy(62)=Starty
6260 HATCH SPACE 4
6270 HATCH ROTATE 45
6280 HATCH ALIGN 130/1500*G+10,31.95
6290 HATCH @P:Capx,Capy
6300 MOVE @P:(G+D(20))/2+80,Height(20)+21
6310 PRINT @P:"H_NOJ_H_H_H_H_H_CAPABILITY"
6320 T9=1
6330 GO TO 3000
6340 END
7000 DATA 0,12.8,25.1,35.3,43.7,50.6,56.6,61.1,66,69.9,73.6,77.2,80.5
7005 Z=103
7010 DATA 83.7,86.6,89.3,91.8,94.1,96.2,98.2,100.1,101.8,103.4,104.9
```

```
7011 DATA 106.3,107.7,109,110.3,111.5,112.6,113.7,114.7,115.8,116.9,118
7012 DATA 119.1,120.2,121.3,122.5,123.7,125,126.3,127.8,129.2,130.7
7013 DATA 132.2,133.8,135.4,137.1,138.8,140.5,142.1,143.7,145.4,147.1
7014 DATA 149.1,151.1,153.1,155.1,156.8,158.3,159.9,161.5,163.2,165.1
7015 DATA 167.1,169,171,173.1,175.3,177.6,180.1,182.7,185.4,188.1,190.9
7016 DATA 193.9,196.9,200,203.1,206.4,209.8,213.3,217,220.9,224.9,229.1
7017 DATA 233.3,237.5,241.7,245.9,250.1,254.6,259.3,264.1,269,274.2
7018 DATA 279.4,284.8,290.1,295.5,0,0
7020 IF P<>1 THEN 7030
7021 GIN @1:Pause1,Pause2
7030 DIM Hx(Z),Hy(Z)
7035 RESTORE 7000
7040 FOR I=1 TO Z
7050    READ Hx(I)
7055    Hy(I)=(I-1)*5
7060 NEXT I
7080 Hy(102)=500
7081 Hy(103)=0
7090 V6=1
7100 RETURN
8000 PRINT "??  ";  !PRINT A KEYBOARD ENTERED LABEL ON PLOTTER
8010 INPUT L$
8020 PRINT @1,17:1.125,2.576
8030 PRINT @1:L$;
8040 GO TO 100
9000 PRINT "# OF TANKS-THEN # OF REPEATS-THEN # OF SECONDS? ";
9010 INPUT L,M,N$  !PRINT TXR LABEL ON PLOTTER
9020 GIN @P:P1,P2
9030 PRINT @1,32:"BY";50
9040 IF N$="0" THEN 9090
9050 PRINT @1,17:1.125,2.576
9060 PRINT @1:"H_H_";L;"Tx";M;"RJ_H_H_H_H_";N$;"s";
9070 MOVE @P:P1,P2
9080 END
9090 PRINT @1:"H_H_";L;"Tx";M;"R";
9100 MOVE @P:P1,P2
9110 END
10000 GIN @1:X8,X9  !DRAW RIGHT ARROW
10010 PRINT @1,17:1.125,2.576
10020 FOR I=0 TO 6
10030    DRAW @1:X8-15+I,X9+6-I
10040    DRAW @1:X8-15+I,X9-6+I
10050    DRAW @1:X8,X9
10060 NEXT I
10070 END
11000 GIN @1:X8,X9  !DRAW LEFT ARROW
11010 PRINT @1,17:1.125,2.576
11020 FOR I=0 TO 6
11030    DRAW @1:X8+15-I,X9+6-I
11040    DRAW @1:X8+15-I,X9-6+I
11050    DRAW @1:X8,X9
11060 NEXT I
11070 END
```

SMOOTHFOOT

This program uses data from the program LDRWIDTH and aligns the footprint data for input to FINALFOOT. Data for each gpc is entered and presented graphically on the computer for modification to eliminate crossing gpc lines, etc.

```
1 GOTO 60000
2 GOTO 63000
3 END
4 GOTO 100
8 GOTO 1000
12 GOTO 50000
16 GOTO 51000
20 GOTO 30000
24 GOTO 10000
28 GOTO 20000
32 GOTO 40000
36 GOTO 55000
40 GOTO 1080
76 GOTO 61000
80 GOTO 62000
100 REM data entry section
110 DELETE L1,L2,L3,L4,L5,F1,F2,F3,F4,F5
120 DIM L1[40,2],L2[40,2],L3[40,2],L4[40,2],L5[40,2],F1[40,2],F2[40,2]
130 DIM F4[40,2],F5[40,2],F3[40,2]
140 F1 = 0
150 F2 = 0
160 F3 = 0
170 F4 = 0
180 F5 = 0
190 L1 = 0
200 L2 = 0
210 L3 = 0
220 L4 = 0
230 L5 = 0
240 CLEAR
250 PRINT "TITLE? ";
260 INPUT T$
270 T$ = "CONAIR DC-6B TANKER 454 " & T$
280 FOR I = 1 TO 40
290   PRINT "ENTER LEADING EDGE FEET THEN ALTITUDE FOR 1 GPC ";
300   INPUT L1[I,1],L1[I,2]
310   IF L1[I,1]=0 THEN 330
320 NEXT I
330 FOR I = 1 TO 40
340   PRINT "ENTER LEADING EDGE FEET THEN ALTITUDE FOR 2 GPC ";
350   INPUT L2[I,1],L2[I,2]
360   IF L2[I,1]=0 THEN 380
370 NEXT I
380 FOR I = 1 TO 40
390   PRINT "ENTER LEADING EDGE FEET THEN ALTITUDE FOR 3 GPC ";
400   INPUT L3[I,1],L3[I,2]
410   IF L3[I,1]=0 THEN 430
420 NEXT I
430 FOR I = 1 TO 40
440   PRINT "ENTER LEADING EDGE FEET THEN ALTITUDE FOR 4 GPC ";
450   INPUT L4[I,1],L4[I,2]
460   IF L4[I,1]=0 THEN 480
```

```
470 NEXT I
480 FOR I = 1 TO 40
490   PRINT "ENTER LEADING EDGE FEET THEN ALTITUDE FOR 5 GPC ";
500   INPUT L5[I,1],L5[I,2]
510   IF L5[I,1]=0 THEN 530
520 NEXT I
530 FOR I = 1 TO 40
540   PRINT "ENTER TRAILING EDGE FEET THEN ALTITUDE FOR 1 GPC ";
550   INPUT F1[I,1],F1[I,2]
560   IF F1[I,1]=0 THEN 580
570 NEXT I
580 FOR I = 1 TO 40
590   PRINT "ENTER TRAILING EDGE FEET THEN ALTITUDE FOR 2 GPC ";
600   INPUT F2[I,1],F2[I,2]
610   IF F2[I,1]=0 THEN 630
620 NEXT I
630 FOR I = 1 TO 40
640   PRINT "ENTER TRAILING EDGE FEET THEN ALTITUDE FOR 3 GPC ";
650   INPUT F3[I,1],F3[I,2]
660   IF F3[I,1]=0 THEN 680
670 NEXT I
680 FOR I = 1 TO 40
690   PRINT "ENTER TRAILING EDGE FEET THEN ALTITUDE FOR 4 GPC ";
700   INPUT F4[I,1],F4[I,2]
710   IF F4[I,1]=0 THEN 730
720 NEXT I
730 FOR I = 1 TO 40
740   PRINT "ENTER TRAILING EDGE FEET THEN ALTITUDE FOR 5 GPC ";
750   INPUT F5[I,1],F5[I,2]
760   IF F5[I,1]=0 THEN 780
770 NEXT I
780 PRINT "DATA ENTERED"
790 GOTO 60000
1000 PRINT
1030 PRINT T$
1040 PRINT "MAXIMUM LENGTH? ";
1050 INPUT M
1055 SET CLIP OFF
1060 SET VIEWPORT 10,120,10,80
1070 SET WINDOW 0,M,0,500
1080 SET LINE COLOR 15
1090 SET TEXT COLOR 15 | SET TEXT STYLE 0 | SET TEXT SIZE 12
1091 CLEAR
1095 MOVE 0,520
1100 TEXT T$
1110 PLOT AXIS 50,100
1120 FOR I = 500 TO 0 STEP -100
1130   MOVE 0,I+5
1140   TEXT ABS(I-500)
1150   MOVE 0,I
1160   DRAW M,I
1170 NEXT I
1180 FOR I = 0 TO M STEP 50
1190   MOVE I-10,0+5
1200   TEXT I
1210 NEXT I
1230 SET LINE COLOR 2
```

```
1240 MOVE 0,500
1250 FOR I = 1 TO 40
1260   IF L1[I,1]=0 THEN 1290
1270   DRAW L1[I,1],500-L1[I,2]
1280 NEXT I
1290 MOVE 0,500
1300 FOR I = 1 TO 40
1310   IF F1[I,1]=0 THEN 1350
1320   DRAW F1[I,1],500-F1[I,2]
1330 NEXT I
1350 SET LINE COLOR 3
1360 MOVE 0,500
1370 FOR I = 1 TO 40
1380   IF L2[I,1]=0 THEN 1410
1390   DRAW L2[I,1],500-L2[I,2]
1400 NEXT I
1410 MOVE 0,500
1420 FOR I = 1 TO 40
1430   IF F2[I,1]=0 THEN 1460
1440   DRAW F2[I,1],500-F2[I,2]
1450 NEXT I
1460 SET LINE COLOR 6
1480 MOVE 0,500
1490 FOR I = 1 TO 40
1500   IF L3[I,1]=0 THEN 1530
1510   DRAW L3[I,1],500-L3[I,2]
1520 NEXT I
1530 MOVE 0,500
1540 FOR I = 1 TO 40
1550   IF F3[I,1]=0 THEN 1580
1560   DRAW F3[I,1],500-F3[I,2]
1570 NEXT I
1580 SET LINE COLOR 14
1600 MOVE 0,500
1610 FOR I = 1 TO 40
1620   IF L4[I,1]=0 THEN 1650
1630   DRAW L4[I,1],500-L4[I,2]
1640 NEXT I
1650 MOVE 0,500
1660 FOR I = 1 TO 40
1670   IF F4[I,1]=0 THEN 1700
1680   DRAW F4[I,1],500-F4[I,2]
1690 NEXT I
1700 SET LINE COLOR 15
1720 MOVE 0,500
1730 FOR I = 1 TO 40
1740   IF L5[I,1]=0 THEN 1770
1750   DRAW L5[I,1],500-L5[I,2]
1760 NEXT I
1770 MOVE 0,500
1780 FOR I = 1 TO 40
1790   IF F5[I,1]=0 THEN 1820
1800   DRAW F5[I,1],500-F5[I,2]
1810 NEXT I
1820 END
10000 REM CHANGE LEADING EDGE
10010 DELETE L
```

```
10020 DIM L[40,2]
10030 HOME
10040 PRINT
10050 PRINT "GPC? ";
10060 INPUT G
10070 ON G GOSUB 10180,10200,10220,10240,10260
10080 FOR I = 1 TO 40
10090   PRINT USING "4D,X,S":L[I,1]
10100 NEXT I
10110 PRINT
10120 PRINT "WHICH ENTRY? ";
10130 INPUT E
10140 PRINT "NEW VALUE? ";
10150 INPUT L[E,1]
10160 ON G GOTO 10280,10300,10320,10340,10360
10170 END
10180 L = L1
10190 RETURN
10200 L = L2
10210 RETURN
10220 L = L3
10230 RETURN
10240 L = L4
10250 RETURN
10260 L = L5
10270 RETURN
10280 L1 = L
10290 END
10300 L2 = L
10310 END
10320 L3 = L
10330 END
10340 L4 = L
10350 END
10360 L5 = L
10370 END
20000 REM CHANGE TRAILING EDGE
20010 DELETE F
20020 DIM F[40,2]
20030 HOME
20040 PRINT
20050 PRINT "GPC? ";
20060 INPUT G
20070 ON G GOSUB 20180,20200,20220,20240,20260
20080 FOR I = 1 TO 40
20090   PRINT USING "4D,X,S":F[I,1]
20100 NEXT I
20110 PRINT
20120 PRINT "WHICH ENTRY? ";
20130 INPUT E
20140 PRINT "NEW VALUE? ";
20150 INPUT F[E,1]
20160 ON G GOTO 20280,20300,20320,20340,20360
20170 END
20180 F = F1
20190 RETURN
20200 F = F2
```

```
20210 RETURN
20220 F = F3
20230 RETURN
20240 F = F4
20250 RETURN
20260 F = F5
20270 RETURN
20280 F1 = F
20290 END
20300 F2 = F
20310 END
20320 F3 = F
20330 END
20340 F4 = F
20350 END
20360 F5 = F
20370 END
30000 REM PRINT OUT SECTION
30005 OPEN #1:"printfile","f"
30010 DELETE K1,K2,L,F
30020 DIM K1[5],K2[5],L[40,2],F[40,2]
30030 K1 = 0
30040 K2 = 0
30050 P$ = "X,4D,2X,4D,2X,S"
30060 CLEAR
30070 PRINT T$ | PRINT #1:T$
30075 PRINT | PRINT #1:
30076 PRINT | PRINT #1:
30080 PRINT "      1            2             3            4";
30081 PRINT #1:"      1            2             3            4";
30090 PRINT "            5"
30091 PRINT #1:"            5"
30100 PRINT "_____________________________________________________";
30101 PRINT #1:"_____________________________________________________";
30110 PRINT "_________"
30111 PRINT #1:"_________"
30120 FOR I = 1 TO 40
30130   IF L5[I,1]=0 AND L4[I,1]=0 AND L3[I,1]=0 AND L2[I,1]=0 THEN 30150
30140   GOTO 30160
30150   IF L1[I,1]=0 THEN EXIT TO 30230
30160   PRINT USING P$:L1[I,1],L1[I,2] | PRINT #1 USING P$:L1[I,1],L1[I,2]
30170   PRINT USING P$:L2[I,1],L2[I,2] | PRINT #1 USING P$:L2[I,1],L2[I,2]
30180   PRINT USING P$:L3[I,1],L3[I,2] | PRINT #1 USING P$:L3[I,1],L3[I,2]
30190   PRINT USING P$:L4[I,1],L4[I,2] | PRINT #1 USING P$:L4[I,1],L4[I,2]
30200   PRINT USING P$:L5[I,1],L5[I,2] | PRINT #1 USING P$:L5[I,1],L5[I,2]
30210   PRINT | PRINT #1:
30220 NEXT I
30230 FOR I = 1 TO 5
30240   ON I GOSUB 10180,10200,10220,10240,10260
30250   ON I GOSUB 20180,20200,20220,20240,20260
30260   FOR J = 1 TO 40
30270     IF L[J,1]=0 THEN EXIT TO 30290
30280   NEXT J
30290   IF J=1 THEN 30310
30300   K1[I] = L[J-1,1]
30310   FOR J = 1 TO 40
30320     IF F[J,1]=0 THEN EXIT TO 30340
```

```
30330   NEXT J
30340   IF J=1 THEN 30360
30350   K2[I] = F[J-1,1]
30360 NEXT I
30370 K1 = K2+K1
30380 K1 = K1/2
30390 FOR I = 1 TO 5
30400   PRINT USING P$:K1[I],0 | PRINT #1 USING P$:K1[I],0
30410 NEXT I
30420 PRINT | PRINT #1:
30430 FOR I = 40 TO 1 STEP -1
30440   IF F5[I,1]=0 AND F4[I,1]=0 AND F3[I,1]=0 AND F2[I,1]=0 THEN 30460
30450   GOTO 30470
30460   IF F1[I,1]=0 THEN 30530
30470   PRINT USING P$:F1[I,1],F1[I,2] | PRINT #1 USING P$:F1[I,1],F1[I,2]
30480   PRINT USING P$:F2[I,1],F2[I,2] | PRINT #1 USING P$:F2[I,1],F2[I,2]
30490   PRINT USING P$:F3[I,1],F3[I,2] | PRINT #1 USING P$:F3[I,1],F3[I,2]
30500   PRINT USING P$:F4[I,1],F4[I,2] | PRINT #1 USING P$:F4[I,1],F4[I,2]
30510   PRINT USING P$:F5[I,1],F5[I,2] | PRINT #1 USING P$:F5[I,1],F5[I,2]
30520   PRINT | PRINT #1:
30530 NEXT I
30540 CALL "lpr printfile"
30550 END
40000 PRINT "WHICH GPC? ";
40010 INPUT G
40020 ON G GOTO 1230,1350,1460,1580,1700
40030 END
50000 REM SAVE DATA ON DISC
50010 PRINT "FILE NAME? ";
50020 INPUT F$
50050 OPEN #1:F$,"F"
50060 WRITE #1:T$,L1,L2,L3,L4,L5,F1,F2,F3,F4,F5
50070 CLOSE
50080 END
51000 REM RECALL STORED DATA
51010 DELETE L1,L2,L3,L4,L5,F1,F2,F3,F4,F5
51020 DIM L1[40,2],L2[40,2],L3[40,2],L4[40,2],L5[40,2],F1[40,2],F2[40,2]
51030 DIM F4[40,2],F5[40,2],F3[40,2]
51040 PRINT "FILE NAME TO BE RECALLED? ";
51050 INPUT F$
51060 OPEN #1:F$,"R"
51070 READ #1:T$,L1,L2,L3,L4,L5,F1,F2,F3,F4,F5
51080 CLOSE
51090 END
55000 PRINT "WHICH GPC? ";
55010 INPUT G
55020 PRINT "WHAT HEIGHT? ";
55030 INPUT H
55040 PRINT "WHAT AMOUNT? ";
55050 INPUT A
55060 ON G GOTO 55100,55200,55300,55400,55500
55070 PRINT "REENTER"
55080 STOP
55100 L1[H/100,1] = L1[H/100,1]+A
55110 F1[H/100,1] = F1[H/100,1]+A
55120 END
55200 L2[H/100,1] = L2[H/100,1]+A
```

```
55210 F2[H/100,1] = F2[H/100,1]+A
55220 END
55300 L3[H/100,1] = L3[H/100,1]+A
55310 F3[H/100,1] = F3[H/100,1]+A
55320 END
55400 L4[H/100,1] = L4[H/100,1]+A
55410 F4[H/100,1] = F4[H/100,1]+A
55420 END
55500 L5[H/100,1] = L5[H/100,1]+A
55510 F5[H/100,1] = F5[H/100,1]+A
55520 END
60000 SET DIALOG COLOR 3
60005 PRINT "USER DEFINABLE KEY  1: ENTER DATA"
60010 PRINT "                    2: DRAW DATA SET"
60020 PRINT "                    3: STORE DATA"
60030 PRINT "                    4: RECALL DATA"
60040 PRINT "                    5: PRINT RESULTS"
60050 PRINT "                    6: CHANGE LEADING EDGE"
60060 PRINT "                    7: CHANGE TRAILING EDGE"
60070 PRINT "                    8: DRAW ANY ONE GPC"
60075 PRINT "                    9: CHANGE BOTH LEADING AND TRAILING"
60080 PRINT "                   10: REDRAW DATA SET"
60090 PRINT "                   19: RECALL A PATDAT FILE"
60100 PRINT "                   20: SAVE THE RECALLED PATDAT FILE"
60110 END
61000 PRINT "FILE? ";
61010 DELETE M1,M2
61020 DIM M1[40],M2[8]
61030 INPUT F$
61040 F$ = "PATDAT" & F$
61050 OPEN #1:F$,"R"
61060 READ #1:M1,M2
61070 CLOSE
61075 CLEAR
61079 FOR J = 0 TO 30 STEP 10
61080   FOR I = 1 TO 10
61081     PRINT USING "3D.3D,S":M1[I+J]
61082   NEXT I
61083   PRINT
61084 NEXT J
61090 SET WINDOW 0,40,0,15
61100 SET VIEWPORT 10,120,10,50
61110 MOVE 0,0
61120 DRAW 40,0
61130 MOVE 0,0
61140 FOR I = 1 TO 40
61150   DRAW I,M1[I]
61160 NEXT I
61170 MOVE 0,1
61180 DRAW 30,1
61190 SET TEXT COLOR 2 | TEXT 1
61200 MOVE 0,2
61210 DRAW 30,2
61220 SET TEXT COLOR 3 | TEXT 2
61230 MOVE 0,3
61240 DRAW 30,3
61250 SET TEXT COLOR 6 | TEXT 3
```

```
61260 MOVE 0,4
61270 DRAW 30,4
61280 SET TEXT COLOR 14 | TEXT 4
61290 MOVE 0,5
61300 DRAW 30,5
61310 SET TEXT COLOR 15 | TEXT 5
61320 MOVE 12,15
61330 TEXT F$
61340 END
62000 OPEN #1:F$,"F"
62010 WRITE #1:M1,M2
62020 CLOSE
62030 END
```

FINAL FOOT

This program accepts data for footprint and width and draws the footprint camera ready on a plotter. Inputs are width for line lengths of 1, 2, 3, 4, and 5 gpc at 100-foot drop height intervals, tension, and downrange position of the footprints.

Tension is the tightness of the smoothing of the data through the points, the lower the value entered, the looser the fit, for most guidelines a value of 1.0 appears to be best.

The length portion of the footprints for each gpc always starts at 0,0 then the value at 100 feet, 200, etc., to 500 feet; then starts up the right side of the footprint at 500 feet, 400 feet, etc. The next to last point is 0 feet and the distance the aircraft flies while the tanks are emptying (evacuation time x speed in feet per second), with the last point being 0,0.

Two files, SIDE and END, containing a digitized outline of the side and end view of the aircraft must also be available to the program. Each is organized as $N, X_1 X_2,,,, X_N):Y_1, Y_2,,,, Y_N$. where N is the number of X, Y data points.

```
1 GO TO 2000
4 GO TO 100
8 GO TO 1000
12 GO TO 1090
16 GO TO 1900
20 K9=0
21 VIEWPORT G8,G9,20,60
22 WINDOW 0,90,0,500
23 GO TO 2500
24 GO TO 2300
28 PRINT "WHAT GPC? ";
29 INPUT Cgpc
30 GO TO Cgpc OF 7500,7600,7700,7800,7900
32 GO TO 5500
36 GO TO 1700
40 GO TO 8200
44 GO TO 6200
48 GO TO 8000
52 GO TO 60000
56 GO TO 63000
60 GO TO 65000
64 GO TO 64000
80 PRINT "ARRAY?";
81 INPUT Ard
82 GO TO Ard OF 51000,52000,53000,54000,55000
89 END
90 DELETE A$
91 DIM A$(300)
92 CALL "MOUNT",0,A$
93 PRINT A$
94 END
100 PAGE
```

```
110 PRINT "INPUT WIDTHS:  GIVE WIDTH FOR EACH CONCENTRATION AT EACH"
120 PRINT "ALTITUDE.  IF NO WIDTH FOR GIVEN ALTITUDE ENTER 0."
130 DIM X1(6),X2(6),X3(6),X4(6),Y1(6),Y2(6),Y3(6),Y4(6),Y9(6)
140 DIM C1(6),C2(6),H1(6),H2(6),H3(6),H4(6),P(20)
150 P9=19
160 X1(1)=0
170 X2(1)=0
180 X3(1)=0
190 X4(1)=0
200 H1(1)=0
210 IMAGE "INPUT WIDTHS FOR ",D," GPC"
220 PRINT USING 210:1
230 FOR I=2 TO 6
240    PRINT (I-1)*100;" FEET ";
250    INPUT X1(I)
260 NEXT I
270 PRINT USING 210:2
280 FOR I=2 TO 6
290    PRINT (I-1)*100;" FEET ";
300    INPUT X2(I)
310 NEXT I
320 PRINT USING 210:3
330 FOR I=2 TO 6
340    PRINT (I-1)*100;" FEET ";
350    INPUT X3(I)
360 NEXT I
370 PRINT USING 210:4
380 FOR I=2 TO 6
390    PRINT (I-1)*100;" FEET ";
400    INPUT X4(I)
410 NEXT I
420 PRINT USING 210:5
430 FOR I=2 TO 6
440    PRINT (I-1)*100;" FEET ";
450    INPUT H1(I)
460 NEXT I
470 X1=X1/2
480 X2=X2/2
490 X3=X3/2
500 X4=X4/2
510 H1=H1/2
520 FOR I=1 TO 6
530    Y9(I)=(I-1)*100
540 NEXT I
550 Y1=500-Y9
560 Y2=Y1
570 Y3=Y1
580 Y4=Y1
590 H2=Y1
600 PRINT "INPUT TENSION (0<T<100)";
610 INPUT P(2)
620 PAGE
630 DELETE X5,Y5,X6,Y6,X7,Y7,X8,Y8,X9,Y9,A2
640 DIM A2(40,2)
650 FOR J=1 TO 5
660    K=0
670    FOR I=1 TO 40
```

```
680       PRINT "ENTER DISTANCE DOWN RANGE THEN DROP HEIGHT FOR ";J;" GP
          C ";
690       INPUT A2(I,1),A2(I,2)
700       A2(I,2)=500-A2(I,2)
710       IF A2(I,2)>501 THEN 740
720       K=K+1
730    NEXT I
740    GOSUB J OF 6670,6800,6910,7020,7130
750    PAGE
760 NEXT J
770 END
1000 PAGE
1010 PRINT "WHAT IS THE LENGTH OF THE GRAPH? ";
1020 INPUT L
1030 PRINT "NUMBER OF COMPARTMENTS? ";
1040 INPUT T$
1050 PRINT "NUMBER OF GALLONS? ";
1060 INPUT L2
1070 REM PRINT "AFTER CPT LABEL? ";
1080 REM INPUT L$
1090 PRINT "ENTER 1 FOR PLOTTER, 32 FOR SCREEN";
1100 INPUT D
1110 Q9=D
1120 IF D<>1 THEN 1200
1130 PRINT "ENTER PLOTTER SPEED: ";
1140 INPUT By
1150 PRINT @1,32:"BY",By
1200 PAGE
1210 REM G8=L/6.29921259843+25
1211 G8=18+L*112/1000
1220 G9=G8+8.74285714286*(1300/800)
1221 G9=90/1000*112+G8
1230 GOSUB 6370
1250 WINDOW 0,1000,0,500
1260 PRINT @1,17:1.125,2.576
1270 VIEWPORT 12,124,20,60
1280 FOR I=500 TO 0 STEP -100
1290    MOVE @D:0,I
1300    RDRAW @D:L,0
1310    RDRAW @D:-L,0
1340    RMOVE @D:0,-5
1350    PRINT @D:"H_H_H_";500-I
1360 NEXT I
1370 MOVE @D:0,0
1380 DRAW @D:0,500
1390 DRAW @D:0,0
1400 Z7=1
1410 FOR I=50 TO L STEP 50
1420    MOVE @D:I,0
1430    IF Z7=3 THEN 1480
1440    RDRAW @D:0,6
1450    RDRAW @D:0,-6
1460    Z7=Z7+1
1470    GO TO 1530
1480    RDRAW @D:0,12
1490    RDRAW @D:0,-12
1500    RDRAW @D:-2.0
```

```
1510    PRINT @D:"J_H_";I
1520    Z7=1
1530 NEXT I
1540 MOVE @D:L/2,0
1550 PRINT @D:"J_J_H_H_H_H_H_H_H_H_H_H_H_H_H_H_H_H_RANGE AND PATTERN LENGTH (FEET)"
1560 IF D=1 THEN 1580
1570 GO TO 1640
1580 MOVE @1:0,250
1590 PRINT "H_H_H_H_"
1600 SET DEGREES
1610 PRINT @1,25:90
1620 PRINT @D:"K_K_H_H_H_H_H_H_H_H_H_H_H_H_H_H_DROP HEIGHT (FEET ABOVE GROUND)"
1630 PRINT @1,25:0
1640 MOVE @D:20,500
1650 PRINT @D:"K_   ";T$;" ";L2;"-GALLON DROP"
1659 PRINT "G_G_G_G_"
1660 END
1700 VIEWPORT G8,G9,20,60
1710 WINDOW 0,90,0,500
1720 AXIS @D:30,500
1725 PRINT @1,17:1.125,2.576
1730 MOVE @D:0,0
1740 PRINT @D:"J_0"
1750 FOR I=30 TO 60 STEP 30
1760    MOVE @D:I,0
1770    RDRAW @D:0,10
1780    RDRAW @D:0,-10
1790    PRINT @D:"J_H_";I
1800 NEXT I
1810 MOVE @D:0,0
1820 PRINT @D:"J_J_HALF-WIDTHJ_H_H_H_H_H_H_H_H_(FEET)"
1830 FOR I=100 TO 500 STEP 100
1840    MOVE @D:0,I
1850    RDRAW @D:90,0
1860    RDRAW @D:-90,0
1870 NEXT I
1880 PRINT "G_"
1890 END
1900 WINDOW 0,1000,0,500
1910 VIEWPORT 12,124,20,60
1920 MOVE @D:0,500
1930 K9=1
1940 07=1
1950 GO TO 2500
1960 END
2000 PAGE
2010 DIM P(20)
2020 C9=0
2030 PRINT "USER DEFINABLE KEYS:"
2040 PRINT
2050 PRINT " 1   ENTER DATA (WIDTHS, TENSION, FILE #'S, etc.)"
2060 PRINT " 2   ENTER PARAMETERS FOR AXES AND DRAW"
2070 PRINT " 3   DRAW AXES FROM PREVIOUSLY ENTERED PARAMETERS"
2080 PRINT " 4   DRAW FOOTPRINTS"
2090 PRINT " 5   DRAW WIDTHS"
2100 PRINT " 6   PRINT LABELS ON PLOTTER"
2110 PRINT " 7   INSERT VALUE INTO ANY GPC FOOTPRINT "
```

```
2120 PRINT " 8   PRINT DATA ON PRINTER"
2130 PRINT " 9   DRAW WIDTH PORTION OF AXES"
2140 PRINT "10   PRINT ID ON LOWER LEFT OF GRAPH"
2150 PRINT "11   PRINT LABELS ON WIDTH CHART WITH LINES"
2160 PRINT "12   PRINT * STATEMENT ON GRAPH"
2165 PRINT "13   PRINT X'S ON FOOTPRINT"
2170 PRINT "14   PRINT X'S ON HALFWIDTH"
2180 PRINT "15   SAVE ENTERED DATA ON SISC "
2181 PRINT "16   RECALL ENTERED DATA FROM DISC "
2189 PRINT "20   CHANGE FOOT PRINT ARRAY"
2190 END
2300 PAGE
2310 PRINT "PRESS RETURN WITH NO ENTRY TO EXIT THIS ROUTINE"
2320 PRINT "POSITION PEN THEN INPUT LABEL AND HIT RETURN. "
2321 PRINT @1,17:1.125,2.576
2330 PRINT
2340 PRINT "INPUT LABEL:";
2350 INPUT A$
2360 IF A$="" THEN 2390
2370 PRINT @D:A$;"H_";A$;"H_";
2380 GO TO 2340
2390 END
2400 P(12)=1
2500 DELETE X,Y,C1,C2
2540 O7=1
2550 IF K9=1 THEN 8260
2560 MOVE @D:0,500
2570 N=6
2580 DIM X(6),Y(6),C1(6),C2(6)
2590 P(12)=1
2600 GO TO O7 OF 4330,4390,4430,4470,4510,4550
2610 END
2620 GO TO O7 OF 8280,8370,8460,8560,8650,8740
2630 DELETE P8
2635 IF N=1 THEN 4550
2636 Adot=SUM(X)
2637 IF Adot=0 THEN 4550
2640 DIM P8(N)
2650 P3=X(2)-X(1)
2660 P5=Y(2)-Y(1)
2670 Q1=SQR(P3*P3+P5*P5)
2680 Q3=P3/Q1
2690 Q5=P5/Q1
2700 IF N>2 THEN 2750
2710 C1=0
2720 C2=0
2730 GO TO 3560
2740 REM  ***FIND SLOPES AT ENDPOINTS***
2750 P2=SQR((X(3)-X(2))^2+(Y(3)-Y(2))^2)
2760 Q4=Q1+P2
2770 P3=-(Q4+Q1)/(Q4*Q1)
2780 P4=Q4/(Q1*P2)
2790 P5=-Q1/(Q4*P2)
2800 P1=P3*X(1)+P4*X(2)+P5*X(3)
2810 P2=P3*Y(1)+P4*Y(2)+P5*Y(3)
2820 P3=SQR(P1*P1+P2*P2)
2830 C1(1)=Q3-P1/P3
```

```
2840 C2(1)=Q5-P2/P3
2850 P2=SQR((X(N-2)-X(N-1))^2+(Y(N-2)-Y(N-1))^2)
2860 P6=SQR((X(N)-X(N-1))^2+(Y(N)-Y(N-1))^2)
2870 Q4=P2+P6
2880 P3=(Q4+P6)/(Q4*P6)
2890 P4=-Q4/(P6*P2)
2900 P5=P6/(Q4*P2)
2910 C1(N)=P3*X(N)+P4*X(N-1)+P5*X(N-2)
2920 C2(N)=P3*Y(N)+P4*Y(N-1)+P5*Y(N-2)
2930 REM  ***SET UP TRI-DIAGONAL SYSTEM***
2940 P8(1)=Q1
2950 Q6=Q1
2960 IF N<3 THEN 3120
2970 P2=2
2980 FOR P1=3 TO N
2990    P3=X(P1)-X(P2)
3000    P5=Y(P1)-Y(P2)
3010    Q2=SQR(P3*P3+P5*P5)
3020    P4=P3/Q2
3030    P6=P5/Q2
3040    C1(P2)=P4-Q3
3050    C2(P2)=P6-Q5
3060    P8(P2)=Q2
3070    Q3=P4
3080    Q5=P6
3090    Q6=Q6+Q2
3100    P2=P1
3110 NEXT P1
3120 P(11)=Q6
3130 P3=SQR(C1(N)^2+C2(N)^2)
3140 C1(N)=C1(N)/P3-Q3
3150 C2(N)=C2(N)/P3-Q5
3160 REM  ***UN-NORMALIZE TENSION FACTOR***
3170 P0=ABS(P(2))*(N-1)/Q6
3180 REM  ***FORWARD ELIMINATION***
3190 P3=P0*P8(1)
3200 P4=EXP(P3)
3210 P5=0.5*(P4-1/P4)
3220 P6=1/(P8(1)*P5)
3230 Q1=P6*(P3*0.5*(P4+1/P4)-P5)
3240 Q5=1/Q1
3250 C1(1)=Q5*C1(1)
3260 C2(1)=Q5*C2(1)
3270 Q4=P6*(P5-P3)
3280 P8(1)=Q5*Q4
3290 IF N<3 THEN 3450
3300 P2=1
3310 FOR P1=2 TO N-1
3320    P3=P0*P8(P1)
3330    P4=EXP(P3)
3340    P5=0.5*(P4-1/P4)
3350    P6=1/(P8(P1)*P5)
3360    Q2=P6*(P3*0.5*(P4+1/P4)-P5)
3370    Q5=1/(Q1+Q2-Q4*P8(P2))
3380    C1(P1)=Q5*(C1(P1)-Q4*C1(P2))
3390    C2(P1)=Q5*(C2(P1)-Q4*C2(P2))
3400    Q4=P6*(P5-P3)
```

```
3410    P8(P1)=Q5*Q4
3420    Q1=Q2
3430    P2=P1
3440 NEXT P1
3450 P2=N-1
3460 Q5=1/(Q1-Q4*P8(P2))
3470 C1(N)=Q5*(C1(N)-Q4*C1(P2))
3480 C2(N)=Q5*(C2(N)-Q4*C2(P2))
3490 REM  ******BACK SUBSTITUTION********************
3500 P2=N
3510 FOR P1=N-1 TO 1 STEP -1
3520    C1(P1)=C1(P1)-P8(P1)*C1(P2)
3530    C2(P1)=C2(P1)-P8(P1)*C2(P2)
3540    P2=P1
3550 NEXT P1
3560 P(13)=P9
3570 DELETE P8
3580 GO TO 3680
3590 IF P9<>19 THEN 3540
3600 GOSUB 64
3610 GO TO 2600
3620 END
3630 GO TO 8 OF 4560,4630,4700,4770,4840,39000
3640 IF P9>19 THEN 100
3650 P9=P9+30
3660 GOSUB 16
3670 REM
3680 REM
3690 P5=0
3700 GOSUB 3900
3710 REM
3720 DELETE I1,I2
3730 DIM I1(400),I2(400)
3740 I1=0
3750 I2=0
3760 FOR P1=1 TO 400
3770    P5=P5+P0
3780    GOSUB 3900
3790    I1(P1)=P6
3800    I2(P1)=P7
3810 NEXT P1
3820 DRAW @D:I1,I2
3821 REM ****************ABOVE IS DRAW ROUTINE************
3840 MOVE @D:0,0
3850 DRAW @D:0,500
3870 IF K9=1 THEN 2620
3880 GO TO 2600
3890 END
3900 Q5=ABS(P(2))*(N-P(12))/P(11)
3910 Q7=ABS(P5*P(11))
3920 IF P5<0 THEN 4000
3930 P3=2
3940 P4=0
3950 IF P5>0 THEN 4000
3960 IF P(12)=0 THEN 4000
3970 P6=X(1)
3980 P7=Y(1)
```

```
3990 RETURN
4000 IF P3=1 THEN 4200
4010 REM  ***DETERMINE WHICH SEGMENT P5 IS MAPPED INTO***
4020 Q8=P3-1
4030 FOR Q6=P3 TO N
4040    Q1=X(Q6)-X(Q8)
4050    Q2=Y(Q6)-Y(Q8)
4060    Q3=SQR(Q1*Q1+Q2*Q2)
4070    IF P4+Q3=>Q7 THEN 4180
4080    P4=P4+Q3
4090    Q8=Q6
4100 NEXT Q6
4110 IF P(12)=0 THEN 4150
4120 P6=X(N)
4130 P7=Y(N)
4140 RETURN
4150 Q6=1
4160 Q8=N
4170 Q3=P(11)-P4
4180 P3=Q6
4190 REM  ***PERFORM INTERPOLATION***
4200 Q1=Q7-P4
4210 Q2=Q3-Q1
4220 Q4=EXP(Q5*Q1)
4230 Q6=0.5*(Q4-1/Q4)
4240 Q5=EXP(Q5*Q2)
4250 Q7=0.5*(Q5-1/Q5)
4260 Q5=Q4*Q5
4270 Q5=0.5*(Q5-1/Q5)
4280 P6=(C1(P3)*Q6+C1(Q8)*Q7)/Q5
4290 P6=P6+((X(P3)-C1(P3))*Q1+(X(Q8)-C1(Q8))*Q2)/Q3
4300 P7=(C2(P3)*Q6+C2(Q8)*Q7)/Q5
4310 P7=P7+((Y(P3)-C2(P3))*Q1+(Y(Q8)-C2(Q8))*Q2)/Q3
4320 RETURN
4330 DELETE X
4340 DIM X(6)
4350 X=X1
4360 Y=Y1
4370 O7=2
4380 GO TO 2630
4390 X=X2
4400 Y=Y2
4410 O7=3
4420 GO TO 2630
4430 X=X3
4440 Y=Y3
4450 O7=4
4460 GO TO 2630
4470 X=X4
4480 Y=Y4
4490 O7=5
4500 GO TO 2630
4510 X=H1
4520 Y=H2
4530 O7=6
4540 GO TO 2630
4550 END
```

```
4560 DELETE X,Y
4570 DIM X(N5),Y(N5)
4580 N=N5
4590 X=X5
4600 Y=Y5
4610 O8=2
4620 GO TO 11410
4630 DELETE X,Y
4640 DIM X(N6),Y(N6)
4650 N=N6
4660 X=X6
4670 Y=Y6
4680 O8=3
4690 GO TO 11410
4700 DELETE X,Y
4710 DIM X(N7),Y(N7)
4720 N=N7
4730 X=X7
4740 Y=Y7
4750 O8=4
4760 GO TO 11410
4770 DELETE X,Y
4780 DIM X(N8),Y(N8)
4790 N=N8
4800 X=X8
4810 Y=Y8
4820 O8=5
4830 GO TO 11410
4840 END
4850 N=N5
4860 GO TO 11220
4870 N=N6
4880 GO TO 11220
4890 N=N7
4900 GO TO 11220
4910 N=N8
4920 GO TO 11220
4930 END
4940 GO TO 1106
4950 VIEWPORT G8,G9,20,60
4960 PRINT 13931
4970 GO TO 1350
4980 VIEWPORT 12,124,20,60
4990 PRINT 13951
5000 GO TO 19
5010 VIEWPORT G8,G9,20,60
5020 PRINT 13971
5030 GO TO 67
5040 VIEWPORT 12,124,20,60
5050 PRINT 13991
5060 GO TO 8200
5070 VIEWPORT G8,G9,20,60
5080 PRINT 14011
5090 WINDOW 0,90,0,500
5100 GO TO 2500
5110 REM WHAT IS THIS FOR?** FIND 9
5120 REM                    * INPUT @33:A$
```

```
5130 REM                    * PRINT A$
5140 REM                    * GO TO 5120
5150 REM ***Subroutine to determine smallest x vlue in array***
5160 M=500
5170 FOR I=1 TO C
5180    M=M MIN A2(I,2)
5190 NEXT I
5200 RETURN
5500 PAGE
5501 PRINT "RET TYPE? ";
5510 INPUT R$
5512 PRINT "J_DEVICE? ";
5514 INPUT D1
5530 PRINT @D1:"L_J_J_J_K_K_";"  ";T$;" ";L2;"-GALLON DROP ";R$
5540 PRINT @D1:"J_J_         WIDTHSJ_"
5550 FOR I=2 TO 6
5560    PRINT @D1: USING 5980:X1(I)*2,X2(I)*2,X3(I)*2,X4(I)*2,H1(I)*2
5570    PRINT @D1: USING 6010:500-Y1(I),500-Y2(I),500-Y3(I),500-Y4(I)
5580    PRINT @D1: USING 5990:500-H2(I)
5590    PRINT @D1:"-------------------------"
5600 NEXT I
5610 DELETE J$
5620 DIM J$(132)
5630 J$="    |        |        |        |        |        |        |"
5640 J$=J$&"        |        |        |        |        |        |"
5650 J$=J$&"        |"
5660 PRINT @D1:"J_J_   DOWNRANGES & HEIGHTSJ_"
5670 FOR I=2 TO N5
5680    PRINT @D1: USING 6000:X5(I,1),"|",500-X5(I,2)
5690 NEXT I
5700 PRINT @D1:
5710 PRINT @D1:J$
5720 FOR I=2 TO N6
5730    PRINT @D1: USING 6000:X6(I,1),"|",500-X6(I,2)
5740 NEXT I
5750 PRINT @D1:
5760 PRINT @D1:J$
5770 FOR I=2 TO N7
5780    PRINT @D1: USING 6000:X7(I,1),"|",500-X7(I,2)
5790 NEXT I
5800 PRINT @D1:
5810 PRINT @D1:J$
5820 FOR I=2 TO N8
5830    PRINT @D1: USING 6000:X8(I,1),"|",500-X8(I,2)
5840 NEXT I
5850 PRINT @D1:
5860 PRINT @D1:J$
5870 FOR I=2 TO N9
5880    PRINT @D1: USING 6000:X9(I,1),"|",500-X9(I,2)
5890 NEXT I
5900 PRINT @D1:
5910 PRINT @D1:J$
5920 FOR I=1 TO 132
5930    PRINT @D1:"_";
5940 NEXT I
5950 PRINT @D1:
5970 END
```

```
5980 IMAGE 5(5D)
5990 IMAGE 5D
6000 IMAGE 4D,A,3D,X,S
6010 IMAGE 4(5D),S
6020 END
6030 INPUT @33:A$
6200 REM DRAW HORIZ LINES AND PRINT GPC ON WIDTH
6205 Ard=0
6210 PRINT @1,17:1.125,2.576
6220 PRINT "POSITION PEN WHERE CHARACTER WILL BE WRITTEN THEN RETURN";
6230 INPUT Q$
6240 GIN @1:H8,H9
6250 PRINT "POSITION PEN ON GRAPH & ENTER CHARACTER TO BE PRINTED"
6260 PRINT "RETURN WITH NO CHARACTER TO EXIT"
6270 INPUT Q$
6290 IF Q$="" THEN 6360
6295 GIN @1:H6,H7
6300 DRAW @1:H8,H9
6330 RMOVE @1:5,-5
6340 PRINT @1:Q$;
6345 MOVE @1:H6,H7
6346 IF Ard=1 THEN 6200
6347 Ard=1
6348 GO TO 6300
6350 GO TO 6200
6360 END
6370 IF C9=1 THEN 6440
6380 OPEN "C123SIDE";1,"R",Z$
6390 READ #1:S6
6410 DELETE Side1,Side2
6420 DIM Side1(S6),Side2(S6)
6425 FOR I=1 TO S6
6430    READ #1:Side1(I),Side2(I)
6435 NEXT I
6436 CLOSE
6437 Side2=Side2+14
6440 VIEWPORT 0,24,60,84
6445 V7=24/112*1000/2
6450 WINDOW -V7,V7,0,V7*2
6460 MOVE @D:Side1(1),Side2(1)
6480 DRAW @D:Side1,Side2
6485 HATCH ROTATE 0
6486 HATCH SPACE 0.1
6491 HATCH @D:Side1,Side2
6520 IF C9=1 THEN 6600
6530 OPEN "C123END";2,"R",Z$
6540 READ #2:S8
6570 DIM Ue1(S8),Ue2(S8)
6571 Ue1=0
6572 Ue2=0
6575 FOR I=1 TO S8
6580    READ #2:Ue1(I),Ue2(I)
6581 NEXT I
6582 CLOSE
6584 Ue2=Ue2+14
6590 C9=1
6600 VIEWPORT G8-12,G8+12,60,84
```

```
6610 REM WINDOW -78.26,78.26,0,139.13
6611 WINDOW -V7,V7,0,V7*2
6620 MOVE @D:Ue1(1),Ue2(1)
6640 DRAW @D:Ue1,Ue2
6650 HATCH @D:Ue1,Ue2
6660 RETURN
6670 DIM X5(K,2)
6690 FOR I=1 TO K
6700    X5(I,1)=A2(I,1)
6710    X5(I,2)=A2(I,2)
6730 NEXT I
6740 C=K
6750 N5=K
6760 GOSUB 5160
6770 IF M<0 THEN 6790
6780 Y1(INT((500-M)/100+2))=M
6790 RETURN
6800 DIM X6(K,2)
6810 FOR I=1 TO K
6820    X6(I,1)=A2(I,1)
6830    X6(I,2)=A2(I,2)
6840 NEXT I
6850 N6=K
6860 C=K
6870 GOSUB 5160
6880 IF M<0 THEN 6900
6890 Y2(INT((500-M)/100+2))=M
6900 RETURN
6910 DIM X7(K,2),Y7(K,2)
6920 FOR I=1 TO K
6930    X7(I,1)=A2(I,1)
6940    X7(I,2)=A2(I,2)
6950 NEXT I
6960 N7=K
6970 C=K
6980 GOSUB 5160
6990 IF M<0 THEN 7010
7000 Y3(INT((500-M)/100+2))=M
7010 RETURN
7020 DIM X8(K,2),Y8(K,2)
7030 FOR I=1 TO K
7040    X8(I,1)=A2(I,1)
7050    X8(I,2)=A2(I,2)
7060 NEXT I
7070 N8=K
7080 C=K
7090 GOSUB 5160
7100 IF M<0 THEN 7120
7110 Y4(INT((500-M)/100+2))=M
7120 RETURN
7130 DIM X9(K,2),Y9(K,2)
7140 FOR I=1 TO K
7150    X9(I,1)=A2(I,1)
7160    X9(I,2)=A2(I,2)
7170 NEXT I
```

```
7180 N9=K
7190 C=K
7200 GOSUB 5160
7210 IF M<0 THEN 7230
7220 H2(INT((500-M)/100+2))=M
7230 RETURN
7500 PRINT "J_J_AFTER WHAT POSITION? ";
7501 INPUT O2
7502 DELETE O1
7503 DIM O1(N5+1,2)
7504 FOR I=1 TO O2
7505    O1(I,1)=X5(I,1)
7506    O1(I,2)=X5(I,2)
7507 NEXT I
7508 PRINT "J_ENTER DOWNRANGE THEN HEIGHT TO BE INSERTED? "
7509 INPUT O1(O2+1,1),O1(O2+1,2)
7510 FOR I=O2+2 TO N5+1
7511    O1(I,1)=X5(I-1,1)
7512    O1(I,2)=X5(I-1,2)
7513 NEXT I
7514 DELETE X5
7515 DIM X5(N5+1,2)
7516 X5=O1
7517 N5=N5+1
7518 END
7519 FOR I=1 TO 5
7520    O1(I,1)=X9(I,1)
7521    O1(I,2)=X9(I,2)
7522 NEXT I
7523 END
7600 PRINT "J_J_AFTER WHAT POSITION? ";
7601 INPUT O2
7602 DELETE O1
7603 DIM O1(N6+1,2)
7604 FOR I=1 TO O2
7605    O1(I,1)=X6(I,1)
7606    O1(I,2)=X6(I,2)
7607 NEXT I
7608 PRINT "J_ENTER DOWNRANGE THEN HEIGHT TO BE INSERTED? "
7609 INPUT O1(O2+1,1),O1(O2+1,2)
7610 FOR I=O2+2 TO N6+1
7611    O1(I,1)=X6(I-1,1)
7612    O1(I,2)=X6(I-1,2)
7613 NEXT I
7614 DELETE X6
7615 DIM X6(N6+1,2)
7616 X6=O1
7617 N6=N6+1
7618 END
7700 PRINT "J_J_AFTER WHAT POSITION? ";
7701 INPUT O2
7702 DELETE O1
7703 DIM O1(N7+1,2)
7704 FOR I=1 TO O2
7705    O1(I,1)=X7(I,1)
7706    O1(I,2)=X7(I,2)
7707 NEXT I
```

```
7708 PRINT "J_ENTER DOWNRANGE THEN HEIGHT TO BE INSERTED? '
7709 INPUT O1(O2+1,1),O1(O2+1,2)
7710 FOR I=O2+2 TO N7+1
7711    O1(I,1)=X7(I-1,1)
7712    O1(I,2)=X7(I-1,2)
7713 NEXT I
7714 DELETE X7
7715 DIM X7(N7+1,2)
7716 X7=O1
7717 N7=N7+1
7718 END
7800 PRINT "J_J_AFTER WHAT POSITION? ";
7801 INPUT O2
7802 DELETE O1
7803 DIM O1(N8+1,2)
7804 FOR I=1 TO O2
7805    O1(I,1)=X8(I,1)
7806    O1(I,2)=X8(I,2)
7807 NEXT I
7808 PRINT "J_ENTER DOWNRANGE THEN HEIGHT TO BE INSERTED? "
7809 INPUT O1(O2+1,1),O1(O2+1,2)
7810 FOR I=O2+2 TO N8+1
7811    O1(I,1)=X8(I-1,1)
7812    O1(I,2)=X8(I-1,2)
7813 NEXT I
7814 DELETE X8
7815 DIM X8(N8+1,2)
7816 X8=O1
7817 N8=N8+1
7818 END
7900 PRINT "J_J_AFTER WHAT POSITION? ";
7901 INPUT O2
7902 DELETE O1
7903 DIM O1(N9+1,2)
7904 FOR I=1 TO O2
7905    O1(I,1)=X9(I,1)
7906    O1(I,2)=X9(I,2)
7907 NEXT I
7908 PRINT "J_ENTER DOWNRANGE THEN HEIGHT TO BE INSERTED? "
7909 INPUT O1(O2+1,1),O1(O2+1,2)
7910 FOR I=O2+2 TO N9+1
7911    O1(I,1)=X9(I-1,1)
7912    O1(I,2)=X9(I-1,2)
7913 NEXT I
7914 DELETE X9
7915 DIM X9(N9+1,2)
7916 X9=O1
7917 N9=N9+1
7918 END
8000 WINDOW 0,1000,0,500
8010 VIEWPORT 12,124,20,60
8020 MOVE @D:0,0
8030 PRINT @1,17:0.9,2.1
8040 PRINT @D:"J_J_J_J_J_J_* INDICATES COVERAGE LEVELS ABOVE ";
8050 PRINT @D:"5 GAL/100 SQ. FT."
8060 PRINT @1,17:1.125,2.576
8070 END
```

```
8200 PAGE
8210 PRINT "ENTER LABEL: ";
8220 INPUT N$
8230 MOVE @1:-720,-410
8240 PRINT @1:N$
8250 END
8260 P(12)=1
8270 GO TO 2620
8280 DELETE X,Y,C1,C2
8290 DIM X(N5),Y(N5),C1(N5),C2(N5)
8300 N=N5
8310 O7=2
8320 FOR I=1 TO N
8330    X(I)=X5(I,1)
8340    Y(I)=X5(I,2)
8350 NEXT I
8360 GO TO 2630
8370 DELETE X,Y,C1,C2
8380 DIM X(N6),Y(N6),C1(N6),C2(N6)
8390 N=N6
8400 O7=3
8410 FOR I=1 TO N
8420    X(I)=X6(I,1)
8430    Y(I)=X6(I,2)
8440 NEXT I
8450 GO TO 2630
8460 DELETE X,Y,C1,C2
8470 DIM X(N7),Y(N7),C1(N7),C2(N7)
8480 N=N7
8490 O7=4
8500 FOR I=1 TO N
8510    X(I)=X7(I,1)
8520    Y(I)=X7(I,2)
8530    O7=4
8540 NEXT I
8550 GO TO 2630
8560 DELETE X,Y,C1,C2
8570 DIM X(N8),Y(N8),C1(N8),C2(N8)
8580 N=N8
8590 O7=5
8600 FOR I=1 TO N
8610    X(I)=X8(I,1)
8620    Y(I)=X8(I,2)
8630 NEXT I
8640 GO TO 2630
8650 DELETE X,Y,C1,C2
8660 DIM X(N9),Y(N9),C1(N9),C2(N9)
8670 N=N9
8680 O7=6
8690 FOR I=1 TO N
8700    X(I)=X9(I,1)
8710    Y(I)=X9(I,2)
8720 NEXT I
8730 GO TO 2630
8740 END
50000 MOVE X5(1,1),X5(1,2)
50010 FOR I=1 TO N5
```

```
50020    DRAW X5(I,1),X5(I,2)
50030 NEXT I
50040 MOVE X6(1,1),X6(1,2)
50050 FOR I=1 TO N6
50060    DRAW X6(I,1),X6(I,2)
50070 NEXT I
50080 MOVE X7(1,1),X7(1,2)
50090 FOR I=1 TO N7
50100    DRAW X7(I,1),X7(I,2)
50110 NEXT I
50120 MOVE X8(1,1),X8(1,2)
50130 FOR I=1 TO N8
50140    DRAW X8(I,1),X8(I,2)
50150 NEXT I
50160 MOVE X9(1,1),X9(1,2)
50170 FOR I=1 TO N9
50180    DRAW X9(I,1),X9(I,2)
50190 NEXT I
50200 END
51000 REM CHANGE X5
51010 PAGE
51020 FOR I=1 TO N5
51030    PRINT USING "3D,2(6D)":I,X5(I,1),X5(I,2)
51040 NEXT I
51050 PRINT "WHICH ELEMENT ENTER ROW THE COL";
51055 PRINT "  ENTER 0 TO EXIT ";
51060 INPUT Row,Col
51065 IF Row=0 THEN 51200
51070 PRINT "ENTER CHANGE";
51080 INPUT Chg
51090 X5(Row,Col)=X5(Row,Col)+Chg
51100 GO TO 51050
51200 END
52000 REM CHANGE X6
52010 PAGE
52020 FOR I=1 TO N6
52030    PRINT USING "3D,2(6D)":I,X6(I,1),X6(I,2)
52040 NEXT I
52050 PRINT "WHICH ELEMENT ENTER ROW THE COL";
52055 PRINT "  ENTER 0 TO EXIT ";
52060 INPUT Row,Col
52065 IF Row=0 THEN 51200
52070 PRINT "ENTER CHANGE";
52080 INPUT Chg
52090 X6(Row,Col)=X6(Row,Col)+Chg
52100 GO TO 52050
53000 REM CHANGE X7
53010 PAGE
53020 FOR I=1 TO N7
53030    PRINT USING "3D,2(6D)":I,X7(I,1),X7(I,2)
53040 NEXT I
53050 PRINT "WHICH ELEMENT ENTER ROW THE COL";
53055 PRINT "  ENTER 0 TO EXIT ";
53060 INPUT Row,Col
53065 IF Row=0 THEN 51200
53070 PRINT "ENTER CHANGE";
53080 INPUT Chg
```

```
53090 X7(Row,Col)=X7(Row,Col)+Chg
53100 GO TO 53050
54000 REM CHANGE X8
54010 PAGE
54020 FOR I=1 TO N8
54030    PRINT USING "3D,2(6D)":I,X8(I,1),X8(I,2)
54040 NEXT I
54050 PRINT "WHICH ELEMENT ENTER ROW THE COL";
54055 PRINT "  ENTER 0 TO EXIT ";
54060 INPUT Row,Col
54065 IF Row=0 THEN 51200
54070 PRINT "ENTER CHANGE";
54080 INPUT Chg
54090 X8(Row,Col)=X8(Row,Col)+Chg
54100 GO TO 54050
55000 REM CHANGE X9
55010 PAGE
55020 FOR I=1 TO N9
55030    PRINT USING "3D,2(6D)":I,X9(I,1),X9(I,2)
55040 NEXT I
55050 PRINT "WHICH ELEMENT ENTER ROW THE COL";
55055 PRINT "  ENTER 0 TO EXIT ";
55060 INPUT Row,Col
55065 IF Row=0 THEN 51200
55070 PRINT "ENTER CHANGE";
55080 INPUT Chg
55090 X9(Row,Col)=X9(Row,Col)+Chg
55100 GO TO 55050
60000 REM PRINT X ON FOOT
60010 FOR I=1 TO N5
60020    MOVE @D:X5(I,1),X5(I,2)
60030    GOSUB 62000
60040 NEXT I
60050 FOR I=1 TO N6
60060    MOVE @D:X6(I,1),X6(I,2)
60070    GOSUB 62000
60080 NEXT I
60090 FOR I=1 TO N7
60100    MOVE @D:X7(I,1),X7(I,2)
60110    GOSUB 62000
60120 NEXT I
60130 FOR I=1 TO N8
60140    MOVE @D:X8(I,1),X8(I,2)
60150    GOSUB 62000
60160 NEXT I
60170 FOR I=1 TO N9
60180    MOVE @D:X9(I,1),X9(I,2)
60190    GOSUB 62000
60200 NEXT I
60210 END
62000 RDRAW @D:3,5
62010 RDRAW @D:-6,-10
62020 RMOVE @D:3,5
62030 RDRAW @D:-3,5
62040 RDRAW @D:6,-10
62050 RETURN
63000 FOR I=1 TO 6
```

```
63010    MOVE @D:X1(I),Y1(I)
63015    IF X1(I)=0 AND Y1(I)=0 THEN 63030
63020    GOSUB 63700
63030 NEXT I
63100 FOR I=1 TO 6
63110    MOVE @D:X2(I),Y2(I)
63115    IF X2(I)=0 AND Y2(I)=0 THEN 63130
63120    GOSUB 63700
63130 NEXT I
63200 FOR I=1 TO 6
63210    MOVE @D:X3(I),Y3(I)
63215    IF X3(I)=0 AND Y3(I)=0 THEN 63230
63220    GOSUB 63700
63230 NEXT I
63300 FOR I=1 TO 6
63310    MOVE @D:X4(I),Y4(I)
63315    IF X4(I)=0 AND Y4(I)=0 THEN 63330
63320    GOSUB 63700
63330 NEXT I
63400 FOR I=1 TO 6
63410    MOVE @D:H1(I),H2(I)
63415    IF H1(I)=0 AND H2(I)=0 THEN 63430
63420    GOSUB 63700
63430 NEXT I
63500 END
63700 RDRAW @D:1,5
63710 RDRAW @D:-2,-10
63720 RMOVE @D:1,5
63730 RDRAW @D:-1,5
63740 RDRAW @D:2,-10
63750 RETURN
63760 END
64000 PRINT "WHAT FILE FOR RETRIEVAL? ";
64005 INPUT B$
64008 DELETE X1,X2,X3,X4,X5,X6,X7,X8,X9,H1,H2,Y1,Y2,Y3,Y4
64009 DIM X1(6),X2(6),X3(6),X4(6),H1(6),H2(6),Y1(6),Y2(6),Y3(6),Y4(6)
64010 OPEN B$;1,"R",C$
64020 READ #1:N5,N6,N7,N8,N9,X1,X2,X3,X4,H1,Y1,Y2,Y3,Y4,H2
64030 DIM X5(N5,2),X6(N6,2),X7(N7,2),X8(N8,2),X9(N9,2)
64040 READ #1:X5,X6,X7,X8,X9
64050 PRINT "TENSION? ";
64060 INPUT P(2)
64070 END
65000 PRINT "WHAT FILE FOR STORAGE? ";
65005 INPUT B$
65006 CALL "FILE",0,B$,C$
65007 PRINT LEN(C$)
65008 IF LEN(C$)<>0 THEN 65020
65010 CREATE B$;1000,0
65020 OPEN B$;1,"F",C$
65030 WRITE #1:N5,N6,N7,N8,N9,X1,X2,X3,X4,H1,Y1,Y2,Y3,Y4,H2
65040 WRITE #1:X5,X6,X7,X8,X9
65060 END
```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George, Charles W.; Johnson, Gregg M. 1990. Developing air tanker performance guidelines. Gen. Tech. Rep. INT-268. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 96 p.

Describes procedures for applying the measured flow history of water or fire retardant from an airtanker and, with the aid of a model (PATSIM), developing a guide for attaining optimum retardant distribution from a specific airplane and tanking system. Text and drawings are assembled into a sample guide for the Evergreen P2V-5 airplane.

KEYWORDS: wildland fire, fire management, fire retardant, retardant patterns, retardant flow rates

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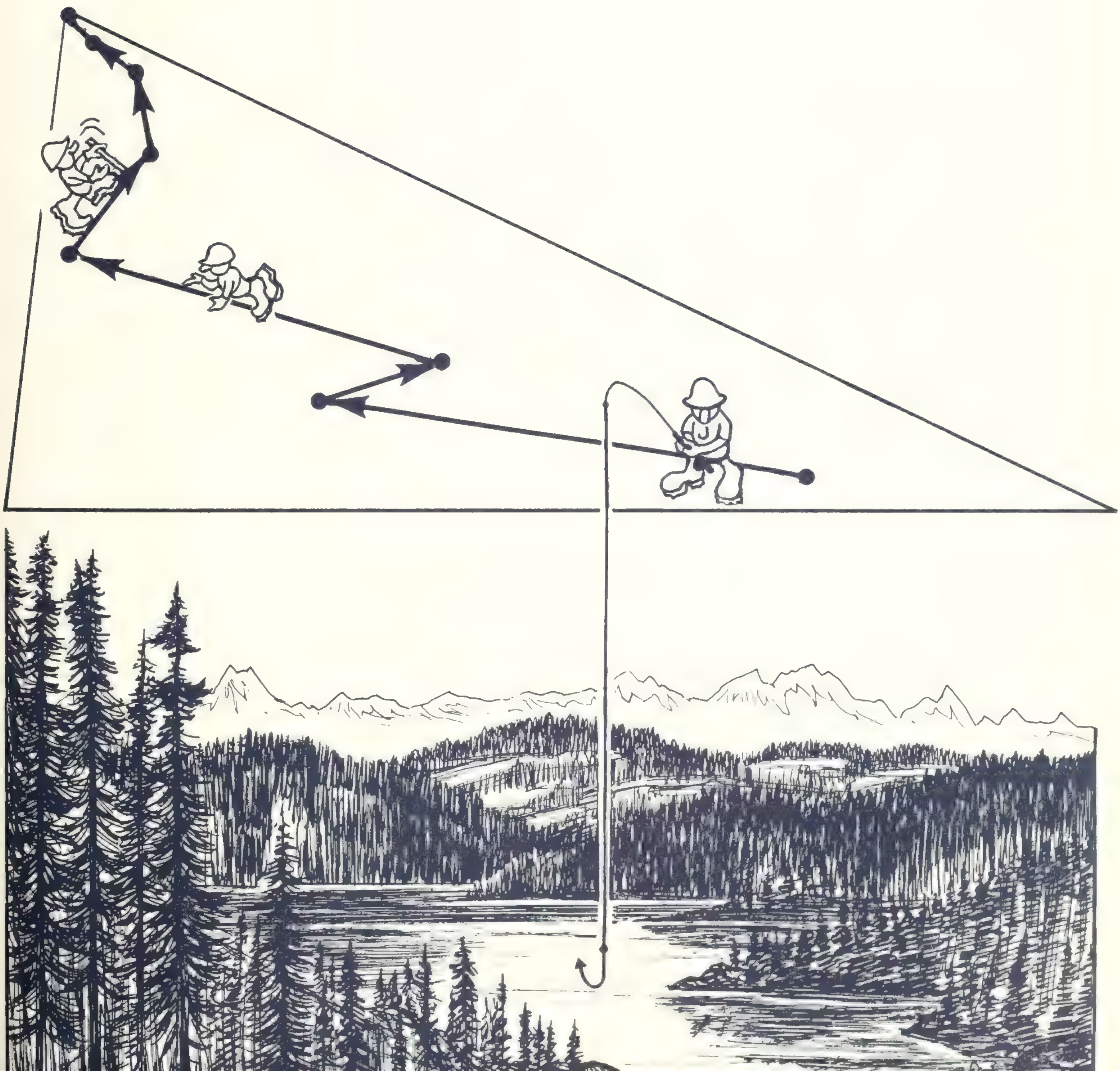
A Programmer's Guide to the Prognosis Optimization Model

Robert A. Monserud
Robert G. Haight



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CONTENTS

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Robert G. Haight

INTRODUCTION

The Prognosis Optimization Model is designed as a research tool to investigate the effects of changes in economic and biological parameters on optimal harvest regimes for mixed-species stands in the Northern Rocky Mountains. The optimization program involves a coordinate-search process called the Method of Hooke and Jeeves (Hooke and Jeeves 1961), and it incorporates without modification version 5.2 of the Stand Prognosis Model (Wykoff et al. 1982; Ferguson and Crookston 1984; Crookston 1985; Ferguson et al. 1986; Hamilton 1986; Wykoff 1986). The optimizer requires the same keyword and treelist input files as the Prognosis Model, as well as an additional input file that defines the size and objective of the harvest problem. The user sets the size of the problem by defining harvest classes that consist of diameter classes, species groups, and periods in which harvesting may take place. The management objective may either be to maximize present value or to maximize volume production. The program returns optimal harvest intensities for the predefined harvest classes. Because of their compatibility, results from the Prognosis Optimization Model complement simulation results obtained with the Stand Prognosis Model.

This guide describes how to compile and run the optimization program using a personal computer. In section 2 we describe the kinds of problems that may be solved and some limitations. Section 3 describes the input requirements and output associated with the optimization model. The input and output for three optimization runs are described in section 4. Section 5 describes how to organize the input files and execute the optimizer. Section 6 describes how to install the optimizer on a personal computer. The file names used in sections 5 and 6 are identical to those contained in the distribution diskette, which may be obtained from the senior author. Readers interested in using the existing executable module for optimization work should read the first six sections. Those interested in changing and compiling the source code should read sections 7 and 8, which describe in detail the source code and compilation instructions.

There are other sources of information related to the Prognosis Optimization Model. We assume that readers are familiar with the operation of the Stand Prognosis Model (see Wykoff et al. 1982; Wykoff 1986; Ferguson and Crookston 1984; Crookston 1985; Ferguson et al. 1986; Hamilton 1986). Those interested in changing the program should also read Wykoff's (1988) instructions for compiling the Prognosis Model on a personal computer. The performance of the Prognosis Optimization Model and its application to various management problems are described by Haight and Monserud (1990a, b).

The following conventions are used to describe programs, variables, and files. Fortran PROGRAM NAMES are written in capital letters; *VARIABLES* in the programs are written in capital italics. Except where noted, Fortran programs are found in MS-DOS files with the same names. When DOS files are described, they are written in capital italics with a suffix *(MAIN.FOR)* Prognosis KEYWORDS are written in small capitals, and they will always be identified as keywords in the text.

THE PROGNOSIS OPTIMIZATION MODEL

The Stand Prognosis Model is designed to simulate the development of forest stands in the Northern Rocky Mountains. The individual tree is the basic unit of projection, and stands with any combination of species and size classes can be accommodated. We use the Inland Empire version 5.2 of the Prognosis Model, which is calibrated for 11 conifer species on 30 habitat types in northern Idaho and northwestern Montana.

The Prognosis Optimization Model is capable of solving harvesting problems that fit two broad stand-management categories: any-aged management and even-aged management. The any-aged stand management problem is to determine the best sequence of species and diameter-class harvesting rates and planting intensities for an existing stand over an infinite time horizon. Harvesting and planting may take place simultaneously in any period, and there are no constraints on the stand size or age structure. Because the sequence of residual diameter distributions may take on any structure, the optimal management regime is any-aged (see Haight and Monserud 1990a for a mathematical description of the problem). In practical applications, an infinite-time-horizon problem cannot be solved. However, sensitivity analysis can be used to determine the impacts of finite-time-horizon approximations. Haight and Monserud (1990a) formulate any-aged management problems in which the stand is eventually clearcut. They find that, with a maximum present value objective and a 4 percent discount rate, horizons greater than 160 years have little impact on optimal management regimes and present values. Haight and Monserud (1990b) determine the impacts of maximum present value and maximum cubic foot volume objectives on optimal any-aged management regimes.

For even-aged management, harvesting problems have two components: the determination of the best thinning regime to employ in an existing stand before it is clearcut (or seedtree harvested), and the determination of the best sequence of thinnings to undertake in the subsequent plantation (or even-aged natural stand). These components are called the conversion problem and the plantation problem, respectively. The optimal plantation regime is found independently of the conversion regime, and it maximizes an infinite series of rents. (Rent is a general term for payoffs that may be measured in present value or volume units depending on the problem objective. Haight and Monserud [1990b] give detailed solutions to even-aged management problems that are formulated with these two objectives.) The best infinite-series plantation is found by comparing the rents from plantations with different rotation ages. The optimal conversion regime maximizes the sum of the rents from conversion and plantation management. The optimal conversion period is found by comparing the rents from conversion and plantation regimes with different conversion ages.

A third category of harvesting problems involves uneven-aged stand management. The goal is to determine the best sequence of selection harvests for a transition regime that terminates with a steady state. The development of methods for solving these constrained problems is in the planning stage, and they are not included in this version of the optimizer.

The coordinate-search algorithm does not guarantee convergence to a globally optimal solution to a given harvesting problem. For both even-aged and any-aged management problems, the Prognosis Optimization Model evaluates harvest regimes that are defined by a set of control variables representing the fractions of trees harvested by diameter class and species group in specified periods. The number of diameter classes and species groups greatly affects convergence. Performance tests show that, for problems with diameter-class and species-class harvest controls defined in two or more periods, the algorithm converges to solutions that may vary considerably in present value and harvest pattern depending on the point at which the search starts and how broadly the control variables are defined (Haight and Monserud 1990a).

From our experience, the performance of the optimizer is improved by defining harvest controls for relatively wide diameter classes and broad species groupings. In the examples presented here, we use three submerchantable diameter classes (0-2, 2-4, and 4-7 inches) and five merchantable diameter classes (7-10, 10-14, 14-18, 18-22, and 22-40 inches). These groupings have proven efficient and considerably reduce the variability resulting from different random starts (Haight and Monserud 1990a). We recommend using species groups in addition to diameter classes only when stumpage price varies by species group. For maximum volume production objectives in which stumpage price is not a concern, the optimizer usually converges to solutions with higher objective function values using just one species group.

Because the optimizer does not guarantee the global optimum, we recommend examining a range of local optima before selecting the best solution to a given problem. In our management studies, we solve each harvesting problem at least three times (and usually six) using different starting points for the harvest controls. Starting points are determined either randomly or from solutions to problems with shorter time horizons.

While the coordinate-search algorithm concentrates on determining optimal harvest intensities by diameter class and species group, planting and site preparation may also be scheduled in any period. These cultural activities are defined as fixed rather than variable inputs. The coordinate-search process determines the optimal harvest proportions for a given set of cultural activities. Repeated application of the optimization program allows comparison of the efficiencies of sets of cultural activities. In an example presented in section 4.3, the Prognosis Optimization Model is used to determine the thinning regime that maximizes merchantable cubic foot volume production for a white pine plantation that starts with 600 seedlings per acre and has a rotation age of 120 years. To determine the best planting density, the optimization needs to be repeated for a wide range of planting densities (see, for example, Haight and Monserud 1990b). Performance tests showed that this procedure provides solutions with higher objective function values than does a procedure in which cultural activities are treated as control variables in addition to the harvest controls (Haight and Monserud 1990a).

3 INPUT REQUIREMENTS AND OUTPUT PRODUCED

3.1 Optimizer Input File

The input file for the optimizer contains records. Each record is a line containing one or more numerical entries. Unless otherwise specified, each entry is assigned a five-space column. Each entry is either an integer, which is right justified within its column, or a real number, which includes a decimal point and may be placed anywhere within its column. For an example of the optimizer input, see figure 1a, section 4.1. Those interested in the Fortran code that defines the input format may refer to *MAIN.FOR* in the appendix. In the following description, variable names are taken directly from the Fortran code.

The first entry in record 1 is an integer (*NRUN*) representing the number of separate optimizations to be made during the execution of the program. Then, on the same record are *NRUN* entries representing random number seeds. These are coded as integer-valued real numbers. Each optimization run uses a different seed. If a seed is positive, the optimization will begin by using a set of random harvest controls generated by that seed. If the seed is negative, the optimization will start by using specified harvest controls (see record type 8, below). This convention allows for combining optimizations that begin with

different random seeds along with an optimization that begins with specific harvest controls, all in the same batch job.

Record 2 has five real-number entries that define the discount rate and parameters for the search procedure (see Haight and Monserud 1990a):

1. *R* is the decimal-valued discount rate (between 0.0 and 1.0).
2. *ALPHA* is the acceleration step used in the pattern search.
3. *DELTA* is the beginning step size for the coordinate search.
4. *EPS* is the minimum step size allowed in the coordinate search before termination.
5. *EPS1* is the minimum improvement in present value resulting from successive coordinate searches allowed before termination.

The discount rate is used to evaluate harvest revenues. When $0.0 < R \leq 1.0$, the objective is to maximize present value. When $R = 0.0$, a maximum volume yield objective is implied. Based on our experience, we suggest using the following values for *ALPHA, DELTA, EPS*, and *EPS1*. Setting *ALPHA* = 0.1 allows for a moderate change in the harvest control values each time a pattern search is performed. Setting *DELTA = 1.0* tests the boundary of each control during the first coordinate search. Setting *EPS = 0.2* and *EPS1 = 999.0* allows five coordinate-search iterations before termination.

Record 3 contains seven integer entries that define the size of the optimization problem and the features of the output:

1. *NUMCYC* is the number of growth periods in the planning horizon. (This has the same value as the NUMCYCLE keyword in Prognosis.)
2. *MERCH* is the index of the minimum merchantable diameter class (for example, if the first three diameter classes contain unmerchantable trees, *MERCH* = 4).
3. *NGROUP* is the number of species groups used to classify trees.
4. *MVOL* is an index for the unit of volume measurement used in evaluating management regimes. When *MVOL* > 0, merchantable board foot volume is used. When *MVOL* < 0, merchantable cubic foot volume is used.
5. *LENGTH* is the length of the growth period (usually 10 years).
6. *NTH* specifies that output be printed every *NTH* growth period.
7. *NOKEY* is zero if the THINDBH keywords describing the optimal regime are not to be written on the optimizer output file.

All entries on record 4 are integers. The first entry is the number of harvest periods *NCUTS*. The remaining entries are the periods (vector *ICUT*) in which harvests are scheduled. Note that the start of period 1 in the optimizer corresponds to year 0 in Prognosis and therefore denotes an immediate harvest. Also note that a clearcut in the final period always takes place and thus is not a variable in the optimization.

The first entry on record 5 is an integer representing the number of diameter-class boundaries (*NCLASS* + 1). Following this entry are *NCLASS* + 1 real numbers representing the boundaries. The first boundary is 0.0, and the last should be larger than any tree you expect the optimizer to see. The optimizer then calculates class midpoints, which are used in the output routine to summarize the diameter distribution. The diameter classes defined by these boundaries classify tree records in Prognosis for the purpose of harvesting. A harvest control variable is defined for each diameter class.

The next set of records (call these record type 6) enters the species codes for the species groups. There is one record for each of the *NGROUP* species groups. The first entry is an integer representing the number of species. The following entries are real numbers representing species identification codes that Prognosis uses (see Wykoff 1986). As a shortcut when all species are assigned to one group (*NGROUP = 1*), simply enter 1 for the number of species in the group and 0.0 as the species code (see fig. 1a, section 4.1).

Prices for each species group are entered with the next set of records (record type 7). Again, there is one record for each species group, and these records are in the same order as the species-group records written above. The entries on each record are real numbers representing prices by diameter class. The prices for unmerchantable diameter classes are negative and represent the cost per tree for precommercial thinning. The prices for merchantable diameter classes represent stumpage prices per thousand board feet or thousand cubic feet, depending on the value of *MVOL*. If merchantable volume maximization is the objective, the prices for the unmerchantable and merchantable classes should be 0.0 and 1.0, respectively (the discount rate *R* should also be 0.0).

The final sets of records (record type 8) enter the initial values for the harvest control array *U1*. First of all, there is one set of records for each species group. The record sets are in the same order as the species-group records written above. There are *NUMCYC* records for each species group. Each of these records contain the harvest control values by diameter class for each period, beginning in the first period. Note that harvests occur at the start of a period and that all optimizations end with a clearcut that capitalizes the growing stock. The entries in each record are real numbers between 0.0 and 1.0 that represent the harvest proportions for the smallest to the largest diameter class. In contrast to previous records, each entry is contained in a seven-space column. If a particular period is not scheduled for cut, the harvest controls are 0.0 for that period. With a positive random number seed, random values between 0.0 and 1.0 are subsequently assigned to the harvest controls in each of the cutting periods specified on record 4.

In summary, the first five records are one line each. The next two sets of records each have *NGROUP* lines. The last set of records has *NGROUP* • *NUMCYC* lines. Thus, the input file should contain 5 + 2 • *NGROUP* + *NGROUP* • *NUMCYC* lines.

3.2 Prognosis Input Files

In addition to the input file for the optimizer, there are two input files required to run the Prognosis Model: a treelist file and a keyword file (see Wykoff et al. 1982 and Wykoff 1986 for a detailed description of the format for these input files). The treelist file contains a list of tree records that describe attributes of the trees in the initial stand. The keyword file (see fig. 1b, section 4.1, for example) contains all the commands that are required to run Prognosis except for the harvest controls, which are read directly into Prognosis during the optimization. In addition, a response file is also utilized. It simply contains the names of the treelist file and the keyword file, thus telling the Prognosis Model where to find its input data.

3.3 Output File

The output file from the optimization program has four parts (see fig. 1c, section 4.1, for example). Part 1 lists input data including the discount rate, the parameters for the coordinate-search process, the random number seed, the thinning periods, and the species numbers for each species group.

Part 2 lists the present value and step size associated with each coordinate search and pattern search. The first present value represents the evaluation of the initial management regime. When the algorithm terminates, the program writes the present value of the final management regime and the number of calls to Prognosis. The initial value of the stand is calculated, printed, and subtracted from the present value of the regime. This optimal net value is then printed. Note that using net rather than total value in an analysis eliminates problems that might arise if several stands (with different initial volumes) are to be examined. It is clearly necessary to work with net value to avoid double counting if sequential optimizations on the same stand over time are concatenated. (Haight and Monserud [1990b] concatenated three successive 160-year optimizations on the same stand in an attempt to examine the steady-state properties of the optimal any-aged regime.) If volume rather than present value is being optimized, the program also prints average annual production (AAP), which is optimal net volume divided by the length of the regime. Note that AAP equals mean annual increment for an even-aged plantation or stand.

In the third part of the output, the optimal harvest regime is described in three tables (for each species group) that describe various diameter distributions over time: the residual stand, the harvested stand, and the percentage of trees harvested. Four stand averages are written after each diameter distribution: trees per acre, basal area per acre, merchantable volume per acre, and value (dollars per acre). Merchantable volume is either in units of 1,000 board feet or 1,000 cubic feet, whichever was specified on input. Note that the estimate of basal area is biased because it is calculated using the midpoint of the associated diameter class (Prognosis does not use a basal area vector); this estimate is used only for display purposes, however.

In part 4 of the output, the program writes the optimal harvest control variables in exactly the format used for input. This allows for efficiently restarting an optimization from the output of a shorter optimization problem. Part 4 also contains a list of THINDBH keywords specifying the appropriate year, diameter class, species, and harvest proportions for use in the Prognosis model. There is no Prognosis output associated with the optimization. To obtain Prognosis output, these THINDBH keywords must be added to the keyword file for a separate Prognosis simulation. The THINDBH keywords will be written in the optimizer output file if *NOKEY* is not zero (see the seventh entry on record 3 of the optimizer input file described in section 3.1).

4 THREE EXAMPLES

This section gives examples of conversion and plantation management problems that can be solved by the Prognosis Optimization Model. The first two examples assume that we start with a mixed-conifer stand in the *Tsuga heterophylla/Clintonia uniflora* habitat type and seek the best thinning regime for the stand before it is clearcut. Example 1 uses a maximum present value objective and a 20-year horizon. Example 2 uses a maximum cubic foot volume objective and a 40-year horizon. Example 3 assumes that we start with bare ground and plant 600 white pine seedlings per acre and seek the best thinning regime for a 120-year plantation.

4.1 Example 1

Suppose we start with the mixed conifer stand described in the Prognosis User's Guide (Wykoff et al. 1982). The problem is to determine the best thinning in period 1 (year 0) assuming that the stand is clearcut at the beginning of period 3 (year 20). Recall that thinnings take place at the start of a period. The objective is to maximize the present value of the stand over the 20-year horizon using a 4 percent discount rate. Trees less than 6 inches are not merchantable and cost $0.10 per tree to cut. Trees greater than 6 inches are worth $100.00 per Mbf independent of species and diameter. Harvest controls are defined for diameter classes, and all species are included in one species group.

The optimizer input file for this problem is listed in figure 1a; here we highlight some of the entries. Because the random number seed (record 1, entry 2) is positive, random proportions will be given to the starting values for the harvest controls. Because *NUMCYC = 2* (record 3, entry 1), there are two growth periods in the planning horizon. Because *MERCH = 4* (record 3, entry 2), there are three unmerchantable diameter classes. There is one species group (record 3, entry 3), and merchantable board foot volume is used to value harvested trees (record 3, entry 4). The length of the growth period is 10 years

(record 3, entry 5). There is one cutting period (record 4, entry 1), which is the first period (record 4, entry 2). Record 5 gives the diameter class bounds; note that there are eight diameter classes. Record 6 indicates one species in the group, and its species code is the shortcut 0 (all species are lumped into one group). Record 7 gives the tree prices (unmerchantable diameter classes) and stumpage prices (merchantable diameter classes). Records 8 and 9 list the initial values for the harvest controls for periods 1 and 2. Note that period 2 harvest controls equal zero because no harvest is scheduled. Although harvest controls for period 1 equal 0, they are subsequently assigned random proportions between 0.0 and 1.0 because harvesting was specified for the first period.

The keyword file used to address Prognosis during the optimization run is listed in figure 1b. The first four lines are based on the stand information given in the Prognosis User's Guide. The NUMTRIP command specifies record tripling in the first two periods.[1] There are two growth projection periods (NUMCYCLE is 2). The regeneration establishment routine is called in the first period (ESTAB is 0). Within this routine, the number of plot replications is 10, and no output is requested. The TREEDATA keyword indicates that Prognosis should look for a treelist file for the description of the initial stand. The last two keywords are required to end the file.

This optimization run takes about 160 seconds on an IBM PS/2 Model 80 with a 20-Mhz processor. During the optimization, there are 31 calls to the Prognosis Model for projection. Output from this example is listed in figure 1c. The optimal strategy for maximizing present value is simple: remove all merchantable trees immediately. The regime produces $216.53 after subtracting the initial value of the stand. Because the optimizer seeks diameter-class harvest controls in only one species group and period, the solution is obtained with a relatively short execution time. Beginning this problem with random harvest controls generated by any integer seed between 1 and 6 results in the same solution.

[1]Prognosis is well-behaved if it has approximately 500-600 tree records to project (W. Wykoff, personal communication). Normal use of the NUMTRIP keyword (tripling twice) is intended to generate adequate variation from stand inventories that contain fewer tree records. We strongly recommend against using the optimizer with the NUMTRIP keyword disabled. If few records are projected, the optimizer may devise an anomalous management regime that favors the few fast growing tree records—which will unrealistically represent a large number of trees per acre. We also recommend using 5-year projection periods until version 6 of the Prognosis Model is released. This modification is necessary to eliminate a height-growth bias on small trees.

Figure 1a—Optimizer input file *FIG1.INP* for example 1.

```
   1    1.   2.
 .04   .1   1.0  0.2 999.
   2    4    1    1   10    1    1
   1    1
   9   0.   2.   4.   7.  10.  14.  18.  22.  40.
   1   0.
 -.1  -.1  -.1  100. 100. 100. 100. 100.
0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
```

Figure 1b—Prognosis keyword file *FIG1.KEY* for example 1.

```
STDIDENT
S248112   HOOKE AND JEEVES DISCRETE STEP; FIGURE 1
DESIGN                                           11.0       1.0
STDINFO         18.0      570.0       0.00        8.0       3.0      34.0
NUMTRIP           2.
NUMCYCLE          2.
ESTAB             0.
MINREP           10.
OUTPUT            0.
END
TREEDATA
PROCESS
STOP
```

Figure 1c—Optimizer output file *FIG1.OUT* for example 1.

```
BOBS2: PROGNOSIS OPTIMIZATION BY THE BOBS

OPTIMIZATION NUMBER      1
INTEREST RATE =          0.040
ACCELERATION STEP =      0.100
BEGINNING STEP SIZE =    1.000
MINIMUM STEP SIZE =      0.200
MINIMUM GAIN =         999.000
RANDOM NUMBER SEED =     1.000

THE OPTIMIZER WILL DETERMINE 1 HARVEST, OCCURRING IN PERIOD  1

SPECIES CODES FOR GROUP 1 ARE  0.

HOOKE & JEEVES COORDINATE SEARCH PROCESS:

PRESENT VALUE =     386.84
 PERFORMED STEP SEARCH WITH DELTA =  1.000
PRESENT VALUE =     588.74
  ACCELERATION STEP NOT SUCCESSFUL
 PERFORMED STEP SEARCH WITH DELTA =  0.500
PRESENT VALUE =     588.74
  ACCELERATION STEP NOT SUCCESSFUL
 PERFORMED STEP SEARCH WITH DELTA =  0.250
PRESENT VALUE =     588.74
  ACCELERATION STEP NOT SUCCESSFUL
 PERFORMED STEP SEARCH WITH DELTA =  0.125
PRESENT VALUE =     588.74

NUMBER OF PROGNOSIS SIMULATIONS =   31

INITIAL VALUE =      372.21 DOLLARS/AC

OPTIMAL PRESENT NET VALUE (PNV) =    216.53 DOLLARS/AC


RESIDUAL TREES PER ACRE FOR SPECIES GROUP  1
```

DBH CLASS	YEAR 0	10	20
1.	245.5	929.8	0.0
3.	54.5	10.9	0.0
5.	136.6	132.6	0.0
8.	0.0	85.1	0.0
12.	0.0	8.7	0.0
16.	0.0	0.0	0.0
20.	0.0	0.0	0.0
31.	0.0	0.0	0.0
TOTAL	437.	1167.	0.
BA/AC	27.	68.	0.
VO/AC	0.00	1.87	0.00
$$/AC	-43.7	79.8	0.0

HARVESTED TREES PER ACRE FOR SPECIES GROUP 1:

DBH CLASS	YEAR 0	10	20
1.	0.0	0.0	2006.8
3.	0.0	0.0	7.4
5.	0.0	0.0	56.2
8.	78.5	0.0	113.3
12.	21.0	0.0	60.7
16.	0.0	0.0	2.2
20.	0.0	0.0	0.0
31.	0.0	0.0	0.0
TOTAL	99.	0.	2246.
BA/AC	47.	0.	116.
VO/AC	4.16	0.00	5.86
$$/AC	415.9	0.0	378.8

PERCENTAGE TREES PER ACRE CUT FOR SPECIES GROUP 1:

DBH CLASS	YEAR 0	10	20
1.	0.00	0.00	100.00
3.	0.00	0.00	100.00
5.	0.00	0.00	100.00
8.	100.00	0.00	100.00
12.	100.00	0.00	100.00
16.	0.00	0.00	100.00
20.	0.00	0.00	0.00
31.	0.00	0.00	0.00

```
OPTIMAL HARVEST CONTROL PARAMETERS FOR SPECIES GROUP  1:
 0.0000 0.0000 0.0000 1.0000 1.0000 0.0000 0.0000 0.0000
 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000

OPTIMAL HARVEST KEYWORDS FOR PROGNOSIS
 (INSERT IN THE KEYWORD FILE)
THINDBH            1.         7.        10.     1.0000
THINDBH            1.        10.        14.     1.0000
```

4.2 Example 2

In this case we start with the same stand, but the problem is to determine the best thinnings in period 1 (year 0) and 3 (year 20) assuming that the stand is clearcut at the beginning of period 5 (year 40). The initial stand is approximately 50 years old. The objective is to maximize the merchantable cubic foot volume produced in the stand over the 40-year horizon. Trees less than 6 inches in diameter are not merchantable. Harvest controls are defined for diameter classes in two species groups. Group 1 includes the two intolerant species, western larch (*Larix occidentalis* Nutt.) and lodgepole pine (*Pinus contorta* Dougl. ex Loud.), and group 2 includes all other species. (Note that we use two species groups for illustration. Because there are no stumpage price differences by species group, superior solutions may be obtained with only one group.)

The input file for the optimizer is listed in figure 2a; note the differences from the input listed in figure 1a. Because we are maximizing merchantable cubic foot volume, the discount rate is 0.0 (record 2, entry 1). With a 10-year projection interval and a 40-year horizon, *NUMCYC = 4* (record 3, entry 1). There are two species groups (record 3, entry 3), and the volume code (record 3, entry 4) is less than zero to indicate a cubic foot volume measure. Record 4 indicates that there are two harvests, in periods 1 and 3. Records 6 and 7 give the number of species and species code for each of the two species groups. Note that there are two lines of prices (records 8 and 9), one for each species group. Unmerchantable tree classes have no value; merchantable tree prices equal 1, so that value is measured in thousand cubic foot units. Finally, note that initial harvest control variable values are entered as a block for each species group. The zeros in periods 1 and 3 will be replaced with random harvest proportions because the random seed is positive.

The Prognosis keyword file for the optimization run is listed in figure 2b. In this case there are four growth projection periods (NUMCYCLE is 4). The regeneration establishment routine is called at the start of periods 1 (year 0) and 3 (year 20).

The optimization run requires about 30 minutes on an IBM PS/2 Model 80 with a 20-Mhz processor. During the optimization, there are 119 calls to the Prognosis Model for stand projection. The output is listed in figure 2c. The optimal regime calls for removing almost all of the merchantable intolerants immediately. The second harvest (year 20) includes a precommercial thinning and the removal of a few of the largest trees in both species groups. In the clearcut in year 40, just over 200 merchantable trees per acre are harvested. After subtracting the initial volume, the stand produces 116 ft^3 per acre per year. As we are about to see in the next example, the stand is obviously understocked.

Figure 2a—Optimizer input file *FIG2.INP* for example 2.

```
   1   5.   6.   7.   8.   9.  10.
  .0   .1  1.0  .2  999.
   4    4    2   -1   10    1    1
   2    1    3
   9   0.   2.   4.   7.  10.  14.  18.  22.  40.
   2   2.   7.
   5   1.   3.   4.   5.   6.
  0.   0.   0.   1.   1.   1.   1.   1.
  0.   0.   0.   1.   1.   1.   1.   1.
0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
```

Figure 2b—Prognosis keyword file *FIG2.KEY* for example 2.

```
STDIDENT
S248112   HOOKE AND JEEVES DISCRETE STEP: FIGURE 2
DESIGN                                        11.0        1.0
STDINFO          18.0      570.0      0.00     8.0        3.0        34.0
NUMTRIP           2.
NUMCYCLE          4.
ESTAB             0.
MINREP           10.
OUTPUT            0.
END
ESTAB            20.
END
TREEDATA
PROCESS
STOP
```

Figure 2c—Optimizer output file *FIG2.OUT* for example 2.

```
BOBS2: PROGNOSIS OPTIMIZATION BY THE BOBS

OPTIMIZATION NUMBER        1
INTEREST RATE =            0.000
ACCELERATION STEP =        0.100
BEGINNING STEP SIZE =      1.000
MINIMUM STEP SIZE =        0.200
MINIMUM GAIN =           999.000
RANDOM NUMBER SEED =       5.000

THE OPTIMIZER WILL DETERMINE  2 HARVESTS.
THEY OCCUR IN PERIODS:   1   3

SPECIES CODES FOR GROUP 1 ARE  2.  7.
SPECIES CODES FOR GROUP 2 ARE  1.  3.  4.  5.  6.

HOOKE & JEEVES COORDINATE SEARCH PROCESS:

PRESENT VALUE =        3.57
 PERFORMED STEP SEARCH WITH DELTA =  1.000
PRESENT VALUE =        5.57
  ACCELERATION STEP NOT SUCCESSFUL
 PERFORMED STEP SEARCH WITH DELTA =  0.500
PRESENT VALUE =        5.57
  ACCELERATION STEP SUCCESSFUL
PRESENT VALUE =        5.57
 PERFORMED STEP SEARCH WITH DELTA =  0.250
PRESENT VALUE =        5.57
  ACCELERATION STEP NOT SUCCESSFUL
 PERFORMED STEP SEARCH WITH DELTA =  0.125
PRESENT VALUE =        5.66

NUMBER OF PROGNOSIS SIMULATIONS =  119

INITIAL VOLUME =              1019.8 CUFT/AC

NET OPTIMAL VOLUME =          4635.5 CUFT/AC

AVERAGE ANNUAL PRODUCTION =  115.9 CUFT/AC/YR


RESIDUAL TREES PER ACRE FOR SPECIES GROUP  1

 DBH      --------YEAR------->
CLASS      0      10      20      30      40
  1.     0.0    30.5     1.9     0.9     0.0
  3.     0.0     0.0     0.0     0.0     0.0
  5.    15.8     0.0     0.0     0.0     0.0
  8.     0.0    15.4     8.2     1.5     0.0
 12.     4.4     4.1     7.8     8.9     0.0
 16.     0.0     0.0     0.0     4.8     0.0
 20.     0.0     0.0     0.0     0.0     0.0
 31.     0.0     0.0     0.0     0.0     0.0
TOTAL    20.     50.     18.     16.      0.
BA/AC     6.      9.      9.     14.      0.
VO/AC   0.11    0.21    0.22    0.34    0.00
$$/AC    0.1     0.2     0.2     0.3     0.0

RESIDUAL TREES PER ACRE FOR SPECIES GROUP  2
 DBH      --------YEAR------->
CLASS      0      10      20      30      40
  1.   245.5   863.9  1800.9  1415.1     0.0
  3.    54.5    42.0     5.4    39.6     0.0
  5.   120.8   107.0    79.0    33.5     0.0
  8.    11.2    71.3    98.5    81.4     0.0
 12.    15.9    21.2    40.7    74.4     0.0
 16.     0.0     4.9     7.1    28.9     0.0
 20.     0.0     0.0     0.0     1.8     0.0
 31.     0.0     0.0     0.0     0.0     0.0
TOTAL   448.   1110.   2032.   1675.      0.
BA/AC    41.     76.    104.    150.      0.
VO/AC   0.39    0.99    1.61    2.82    0.00
$$/AC    0.4     1.0     1.6     2.8     0.0

HARVESTED TREES PER ACRE FOR SPECIES GROUP  1:

 DBH      --------YEAR------->
CLASS      0      10      20      30      40
  1.     0.0     0.0    33.2     0.0    13.7
  3.     0.0     0.0     0.0     0.0     0.0
  5.     0.0     0.0     0.0     0.0     0.0
  8.    64.3     0.0     0.0     0.0     0.0
 12.     0.6     0.0     1.1     0.0     3.5
 16.     0.0     0.0     1.4     0.0    10.7
 20.     0.0     0.0     0.0     0.0     0.0
 31.     0.0     0.0     0.0     0.0     0.0
TOTAL    65.      0.     36.      0.     28.
BA/AC    26.      0.      3.      0.     18.
VO/AC   0.49    0.00    0.09    0.00    0.43
$$/AC    0.5     0.0     0.1     0.0     0.4

HARVESTED TREES PER ACRE FOR SPECIES GROUP  2:

 DBH      --------YEAR------->
CLASS      0      10      20      30      40
  1.     0.0     0.0   213.2     0.0  1568.0
  3.     0.0     0.0     0.8     0.0    84.5
  5.     0.0     0.0     0.0     0.0     8.7
  8.     3.0     0.0     0.0     0.0    73.8
 12.     0.0     0.0     0.0     0.0    71.5
 16.     0.0     0.0     7.3     0.0    41.7
 20.     0.0     0.0     0.6     0.0     9.9
 31.     0.0     0.0     0.0     0.0     0.4
TOTAL     3.      0.    222.      0.   1859.
BA/AC     1.      0.     13.      0.    181.
VO/AC   0.03    0.00    0.32    0.00    4.30
$$/AC    0.0     0.0     0.3     0.0     4.3

PERCENTAGE TREES PER ACRE CUT FOR SPECIES GROUP  1:

 DBH      --------YEAR------->
CLASS      0      10      20      30      40
  1.    0.00    0.00   94.65    0.00  100.00
  3.    0.00    0.00    0.00    0.00  100.00
  5.    0.00    0.00    0.00    0.00    0.00
  8.  100.00    0.00    0.00    0.00    0.00
 12.   12.50    0.00   12.50    0.00  100.00
 16.    0.00    0.00  100.00    0.00  100.00
 20.    0.00    0.00    0.00    0.00    0.00
 31.    0.00    0.00    0.00    0.00    0.00
```

Figure 2c (Con.)

PERCENTAGE TREES PER ACRE CUT FOR SPECIES GROUP 2:

DBH CLASS	YEAR 0	10	20	30	40
1.	0.00	0.00	10.58	0.00	100.00
3.	0.00	0.00	12.50	0.00	100.00
5.	0.00	0.00	0.00	0.00	100.00
8.	20.92	0.00	0.00	0.00	100.00
12.	0.00	0.00	0.00	0.00	100.00
16.	0.00	0.00	50.60	0.00	100.00
20.	0.00	0.00	100.00	0.00	100.00
31.	0.00	0.00	0.00	0.00	100.00

OPTIMAL HARVEST CONTROL PARAMETERS FOR SPECIES GROUP 1:

0.0000	0.0000	0.0000	1.0000	0.1250	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.9465	0.0000	0.0000	0.0000	0.1250	1.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

OPTIMAL HARVEST CONTROL PARAMETERS FOR SPECIES GROUP 2:

0.0000	0.0000	0.0000	0.2092	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.1058	0.1250	0.0000	0.0000	0.0000	0.5060	1.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

OPTIMAL HARVEST KEYWORDS FOR PROGNOSIS
(INSERT IN THE KEYWORD FILE)

THINDBH	1.	7.	10.	1.0000	2.
THINDBH	1.	7.	10.	1.0000	7.
THINDBH	1.	7.	10.	0.2092	1.
THINDBH	1.	7.	10.	0.2092	3.
THINDBH	1.	7.	10.	0.2092	4.
THINDBH	1.	7.	10.	0.2092	5.
THINDBH	1.	7.	10.	0.2092	6.
THINDBH	1.	10.	14.	0.1250	2.
THINDBH	1.	10.	14.	0.1250	7.
THINDBH	21.	0.	2.	0.9465	2.
THINDBH	21.	0.	2.	0.9465	7.
THINDBH	21.	0.	2.	0.1058	1.
THINDBH	21.	0.	2.	0.1058	3.
THINDBH	21.	0.	2.	0.1058	4.
THINDBH	21.	0.	2.	0.1058	5.
THINDBH	21.	0.	2.	0.1058	6.
THINDBH	21.	2.	4.	0.1250	1.
THINDBH	21.	2.	4.	0.1250	3.
THINDBH	21.	2.	4.	0.1250	4.
THINDBH	21.	2.	4.	0.1250	5.
THINDBH	21.	2.	4.	0.1250	6.
THINDBH	21.	10.	14.	0.1250	2.
THINDBH	21.	10.	14.	0.1250	7.
THINDBH	21.	14.	18.	1.0000	2.
THINDBH	21.	14.	18.	1.0000	7.
THINDBH	21.	14.	18.	0.5060	1.
THINDBH	21.	14.	18.	0.5060	3.
THINDBH	21.	14.	18.	0.5060	4.
THINDBH	21.	14.	18.	0.5060	5.
THINDBH	21.	14.	18.	0.5060	6.
THINDBH	21.	18.	22.	1.0000	1.
THINDBH	21.	18.	22.	1.0000	3.
THINDBH	21.	18.	22.	1.0000	4.
THINDBH	21.	18.	22.	1.0000	5.
THINDBH	21.	18.	22.	1.0000	6.

4.3 Example 3

The following example is used by Haight and Monserud (1990b) to develop optimal white pine plantation management regimes. The objective is to maximize cubic foot volume production over a 120-year horizon in which thinnings may take place every 20 years beginning in year 20. The fixed silvicultural inputs are defined in the Prognosis keyword file (fig. 3b). Using the same stand and site parameters as in the previous example (see the STDINFO keyword), this run begins with bare ground and plants 600 white pine seedlings per acre after site preparation is completed. During the 120-year projection (24 cycles of 5 years), the regeneration establishment model is called if thinning removes at least 20 ft^2 per acre. If the thinning leaves less than 80 ft^2 per acre then a regeneration cut is assumed to have occurred; site preparation is performed, and the establishment and development of both advanced and subsequent regeneration are simulated. If the thinning leaves at least 80 ft^2 per acre then site preparation is not done, and only advanced regeneration is simulated. Because we start with bare ground (note the NOTREES keyword), we have taken out the TREEDATA keyword.

The optimizer input file is listed in figure 3a. Unlike the previous examples, this optimization does not start with random harvest controls (on record 1, entry 2 is negative). Instead, the run begins with the optimal 100-year regime specified in the block of harvest controls at the end of the file. When the optimization problem is complicated, this sequential strategy for specifying initial conditions is far more efficient than beginning with many random starts.

This optimization problem requires 177 calls to Prognosis and takes 112 minutes on a 20-Mhz personal computer. Output describing the optimal plantation management is listed in figure 3c. The optimal regime, which produces 163 ft^3 per acre per year, is discussed in detail by Haight and Monserud (1990b).

Figure 3a—Optimizer input file *FIG3.INP* for example 3.

```
   1  -1.
  .0   .1  1.0  .2  999.
  24    4    1   -1    5    2    1
   5    5    9   13   17   21
   9   0.   2.   4.   7.  10.  14.  18.  22.  40.
   1   0.
  0.   0.   0.   1.   1.   1.   1.   1.
0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
1.0000 0.5262 0.0224 0.8346 0.0000 0.0000 0.0000 0.0000
0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
0.1250 0.0000 0.0000 0.0000 0.1250 0.5000 0.0000 0.0000
0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
1.0000 0.0000 0.0000 0.7500 0.0000 0.0000 0.3750 0.0000
0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
0.0000 0.0000 0.0000 0.8750 1.0000 0.0000 0.0000 0.0000
0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
```

Figure 3b—Prognosis keyword file *FIG3.KEY* for example 3.

```
STDIDENT
S248112       HOOKE AND JEEVES;   PLANT 600 WWP & GROW 120 YEARS
STDINFO         18.0      570.0       0.00        8.0        3.0       34.0
NUMTRIP          5.
NOTREES
TIMEINT                    5.
NUMCYCLE        24.
ESTAB            0.
PLANT            2.        1.         600.
MECHPREP         1.       50.
BURNPREP         1.       30.
MINREP          10.
OUTPUT           0.
END
COMMENT
Schedule a normal call to ESTAB whenever a regeneration cut occurs:
END
IF
 (FRAC((CYCLE-1)/4 ) EQ 0) AND (CYCLE NE 1)         &
  AND ( ((BBA-ABA) GT 20) AND (ABA LT 80) )
THEN
ESTAB
MECHPREP          0.        20.
END
ENDIF
COMMENT
Otherwise pump in advanced regeneration every 20 years:
END
IF
 (FRAC((CYCLE-1)/4 ) EQ 0) AND (CYCLE NE 1)          &
  AND  ( ((BBA-ABA) LE 20) OR (ABA GE 80) )
THEN
ESTAB
MECHPREP          0.        0.
TALLYONE          3.
END
ENDIF
PROCESS
STOP
```

Figure 3c—Optimizer output file *FIG3.OUT* for example 3.

```
BOBS2: PROGNOSIS OPTIMIZATION BY THE BOBS

OPTIMIZATION NUMBER      1
INTEREST RATE =          0.000
ACCELERATION STEP =      0.100
BEGINNING STEP SIZE =    1.000
MINIMUM STEP SIZE =      0.200
MINIMUM GAIN =         999.000
RANDOM NUMBER SEED =    -1.000

THE OPTIMIZER WILL DETERMINE  5 HARVESTS.
THEY OCCUR IN PERIODS:   5   9  13  17  21

SPECIES CODES FOR GROUP 1 ARE  0.

HOOKE & JEEVES COORDINATE SEARCH PROCESS:

PRESENT VALUE =       19.10
 PERFORMED STEP SEARCH WITH DELTA =  1.000
PRESENT VALUE =       19.47
  ACCELERATION STEP NOT SUCCESSFUL
 PERFORMED STEP SEARCH WITH DELTA =  0.500
PRESENT VALUE =       19.53
  ACCELERATION STEP SUCCESSFUL
PRESENT VALUE =       19.53
 PERFORMED STEP SEARCH WITH DELTA =  0.250
PRESENT VALUE =       19.53
  ACCELERATION STEP NOT SUCCESSFUL
 PERFORMED STEP SEARCH WITH DELTA =  0.125
PRESENT VALUE =       19.53

NUMBER OF PROGNOSIS SIMULATIONS =  177

INITIAL VOLUME =                0.0 CUFT/AC

NET OPTIMAL VOLUME =        19531.1 CUFT/AC

AVERAGE ANNUAL PRODUCTION =  162.8 CUFT/AC/YR
```

RESIDUAL TREES PER ACRE FOR SPECIES GROUP 1

DBH	--------YEAR------->											
CLASS	0	10	20	30	40	50	60	70	80	90	100	110	120
1.	0.0	1976.8	0.0	1950.2	2871.6	2441.1	0.0	686.6	609.2	866.3	725.0	730.5	0.0
3.	0.0	0.0	156.1	22.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.9	0.0
5.	0.0	0.0	249.9	197.9	92.3	33.8	2.1	0.6	0.0	0.0	0.0	0.0	0.0
8.	0.0	0.0	1.1	155.8	198.3	135.5	21.9	14.5	6.0	2.3	0.0	0.0	0.0
12.	0.0	0.0	0.0	11.9	69.3	143.1	155.9	105.3	0.0	2.9	1.8	1.4	0.0
16.	0.0	0.0	0.0	0.0	2.6	22.2	53.6	65.8	65.0	45.1	23.7	12.0	0.0
20.	0.0	0.0	0.0	0.0	0.0	1.0	2.7	20.9	40.7	41.8	46.5	36.4	0.0
31.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	1.4	14.3	25.7	41.7	0.0
TOTAL	0.	1977.	407.	2338.	3234.	2777.	236.	894.	722.	973.	823.	834.	0.
BA/AC	0.	11.	49.	115.	167.	218.	212.	234.	193.	237.	275.	321.	0.
VO/AC	0.00	0.00	0.00	1.18	3.21	5.44	7.02	9.03	8.33	10.49	12.35	14.34	0.00
$$/AC	0.0	0.0	0.0	1.2	3.2	5.4	7.0	9.0	8.3	10.5	12.4	14.3	0.0

HARVESTED TREES PER ACRE FOR SPECIES GROUP 1:

DBH	--------YEAR------->											
CLASS	0	10	20	30	40	50	60	70	80	90	100	110	120
1.	0.0	0.0	3221.8	0.0	0.0	0.0	1986.5	0.0	0.0	0.0	0.0	0.0	485.6

Figure 3c (Con.)

3.	0.0	0.0	173.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	111.2
5.	0.0	0.0	5.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8.	0.0	0.0	5.7	0.0	0.0	0.0	65.8	0.0	0.9	0.0	0.6	0.0	0.0
12.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	74.3	0.0	2.2	0.0	1.1
16.	0.0	0.0	0.0	0.0	2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.1
20.	0.0	0.0	0.0	0.0	0.0	0.0	1.6	0.0	0.0	0.0	0.0	0.0	29.9
31.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	52.0
TOTAL	0.	0.	3407.	0.	3.	0.	2054.	0.	75.	0.	3.	0.	683.
BA/AC	0.	0.	29.	0.	4.	0.	40.	0.	59.	0.	2.	0.	351.
VO/AC	0.00	0.00	0.02	0.00	0.10	0.00	0.74	0.00	2.62	0.00	0.07	0.00	15.99
$$/AC	0.0	0.0	0.0	0.0	0.1	0.0	0.7	0.0	2.6	0.0	0.1	0.0	16.0

PERCENTAGE TREES PER ACRE CUT FOR SPECIES GROUP 1:

DBH CLASS	--------YEAR-------> 0	10	20	30	40	50	60	70	80	90	100	110	120
1.	0.00	0.00	100.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	100.00
3.	0.00	0.00	52.62	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00
5.	0.00	0.00	2.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8.	0.00	0.00	83.46	0.00	0.00	0.00	75.00	0.00	12.50	0.00	100.00	0.00	0.00
12.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	55.00	0.00	100.00
16.	0.00	0.00	0.00	0.00	50.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00
20.	0.00	0.00	0.00	0.00	0.00	0.00	37.50	0.00	0.00	0.00	0.00	0.00	100.00
31.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00

OPTIMAL HARVEST CONTROL PARAMETERS FOR SPECIES GROUP 1:

0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1.0000	0.5262	0.0224	0.8346	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.5000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1.0000	0.0000	0.0000	0.7500	0.0000	0.0000	0.3750	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.1250	1.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	1.0000	0.5500	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

OPTIMAL HARVEST KEYWORDS FOR PROGNOSIS
(INSERT IN THE KEYWORD FILE)

THINDBH	21.	0.	2.	1.0000
THINDBH	21.	2.	4.	0.5262
THINDBH	21.	4.	7.	0.0224
THINDBH	21.	7.	10.	0.8346
THINDBH	41.	14.	18.	0.5000
THINDBH	61.	0.	2.	1.0000
THINDBH	61.	7.	10.	0.7500
THINDBH	61.	18.	22.	0.3750
THINDBH	81.	7.	10.	0.1250
THINDBH	81.	10.	14.	1.0000
THINDBH	101.	7.	10.	1.0000
THINDBH	101.	10.	14.	0.5500

5 PROGRAM EXECUTION AND SIZE LIMITS

As we described in sections 3.1 and 3.2, there are several files required to run the Prognosis Optimization Model. Here we describe how to organize these files and execute the optimizer. File names correspond to those contained in the distribution diskette. Installing the program is the subject of section 6.

We recommend executing the Prognosis Optimization Model with a DOS batch file such as *FIG1.BAT* with the following commands:

DT
COPY *FIG1.INP* *BOBS.INP*
COPY *FIG1.KEY* *TEST.KEY*
OPTGROW < *TEST.RSP*
COPY *BOBS.OUT* *FIG1.OUT*
DT

FIG1.BAT contains the set of commands needed to solve the harvest problem discussed in example 1 above. The DT execute commands print the date and time at the start and end of the optimization. File *FIG1.INP* contains the input data for the optimizer (fig. 1a). It is copied to file *BOBS.INP*, which the optimizer will read for input parameters. File *FIG1.KEY* contains the Prognosis keywords (fig. 1b), and it is copied to file *TEST.KEY*, which Prognosis will read for keywords. The command *OPTGROW* executes the optimizer. This command points to response file *TEST.RSP*, which contains file names for the Prognosis treelist file *TEST.TRE* and keyword file *TEST.KEY*. After executing the *OPTGROW* command, the output file *BOBS.OUT* is copied to *FIG1.OUT* (fig. 1c), which will not be written over by a subsequent execution of the optimizer (as *BOBS.OUT* will be).

Now that we know what is contained in the input files, it is time to make the optimization run. To do this, simply type the command:

FIG1

which initiates execution of the batch file that contains the commands for running the program.

Limits to the size of the optimization problem that can be solved are affected by the size of the arrays declared in the optimization program (see the appendix; Haight and Monserud [1990a] also discuss practical limits on the complexity of optimization problems that can be solved). Currently the maximum numbers of periods, diameter classes, and species groups are 33, 8, and 3, respectively. If these are changed, be sure to modify array size declarations in each of the following optimization routines: MAIN and subroutines CONTROL, OUT, STATE, VALUE, and GKEY (all of which are in *OPT.FOR*), and PMAIN2 (which is in *PMAIN.FOR*).

Limits to the size of the problem are also affected by the maximum number of keywords (1,200) and keyword parameters (6,000) that may be processed by the Prognosis Model. In a keyword file for a thinning regime, THINDBH keywords take up the most space. Whenever harvesting takes place by species group, a THINDBH keyword is created for each diameter class, tree species, and period in which harvesting may occur. Further, there are five parameters on each THINDBH keyword. To see how rapidly these accumulate, suppose we define an optimization problem with 10 tree species among three groups, eight diameter classes, and 15 cutting periods. Then, there are 10 x 8 x 15 = 1,200 keywords and 1,200 x 5 = 6,000 parameters. Because there are several other keywords that define the harvest regime (ESTAB, for example), this keyword file is too large for the Prognosis Model, with uncertain consequences. The Prognosis Model may either terminate prematurely or not process keywords beyond the upper limit. Thus, it is important to make sure the problem size is within these boundaries.

Execution time depends on the size of the problem. Example 1, which includes one thinning period, eight diameter classes, one species group, and a 20-year horizon, requires about 3 minutes on a 386 personal computer (an IBM PS/2 Model 80) with a 20-Mhz processor. Problems with thinnings every 20 years and 40-, 60-, and 160-year time horizons require around 25, 50, and 240 minutes, respectively. For more than one species group, multiply these times by the number of groups. Execution times on other personal computers should be approximately proportional to the ratio of the processor frequencies. For example, the 3-minute run discussed above took 3.8 minutes on a Compaq 386 with a 16-Mhz clock.

6 PROGRAM INSTALLATION

There are two ways to get an executable version of the optimizer on your system. The first—and by far the simplest—is to extract it from the archived executable code stored on the distribution diskette. This approach is fine if you simply want to run the optimizer and do not need to modify anything in the program. This section explains this choice. The second way to get an executable program is to build it from the source code contained on the distribution diskette. This procedure is explained in section 8.

For openers, we assume that MS-DOS is the operating system on your personal computer (we will occasionally use the DOS wildcard character *). Begin by copying *OPTGROW.ARC*, *ARC.DOC*, and *ARC.EXE* files from the program diskette onto a directory dedicated to running the optimizer. The Prognosis Optimization Model and input files for three examples are compactly written onto *OPTGROW.ARC* using a public domain archiving utility called ARC that is distributed by Systems Enhancement Associates, Wayne, NJ. This utility is stored in file *ARC.EXE* with documentation given in *ARC.DOC*. The *SOURCE*.ARC* files on the distribution diskette contain the source code for the Prognosis optimizer and are needed only if you plan to create a new executable program. Unload all files from *OPTGROW.ARC* with the ARC extraction command:

ARC X OPTGROW

The extracted executable module, *OPTGROW.EXE*, will require about 529K. The three overlays are *ESESTAB.OVL*, *ESGROWTH.OVL*, and *ESINPUT.OVL*. You will find that the following input and batch files also have been extracted: *TEST.RSP*, *TEST.TRE*, *FIG*.KEY*, *FIG*.INP*, *FIG*.BAT*, *DT.EXE*, and *UNLOAD.BAT*.

These are all the files needed to run the example problems. (Note that the last file is used only if you are going to extract the source code as discussed in section 8.)

7 PROGRAM STRUCTURE

This section describes the structure of the source code for the Prognosis Optimization Model, which is listed in the appendix. The driver program for stand optimization (program MAIN) contains a coordinate-search process that repeatedly evaluates and attempts to improve the value of the harvest regime for a given stand. The harvest regime specifies the proportions (fractions between 0.0 and 1.0) of trees cut by size class, species group, and period. These proportions are called "harvest controls." During the course of an optimization the Prognosis Model is called as a subroutine to project the stand as a function of the harvest controls. Except where noted, no changes have been made in the Prognosis code. The variables in MAIN are independent of those in Prognosis and are defined in the program listing. The MAIN program contains three blocks: initialization, search process, and writing the results. The first two blocks are described here, and the output block is described in section 3.3. When reading the descriptions of these blocks, make sure to look at the source code and comments listed in the appendix.

7.1 Initialization

The initialization phase involves reading input parameters that control the optimization, opening the Prognosis files, initializing the harvest controls, and evaluating the harvest regime.

The optimization begins by reading control parameters for the optimizer (see fig. 1a) on unit 25. These parameters are discussed in detail in section 3.1. Among other things, they include the diameter classes, species groups, and periods in which harvesting may take place, the stumpage prices used to value harvests, and the initial values given to the harvest controls. After optimizer initialization, an outer loop is entered that repeats the optimization run with different seeds for generating random starting points for the harvest controls.

The next step involves opening the Prognosis files. Before we describe this step, a little background information is needed. During the course of the optimization, the Prognosis Model is repeatedly called as a subroutine to project candidate management regimes. These simulations are controlled by the keyword file (unit 5) and the treelist file (unit 2), which must be present in addition to the input file for the optimizer (see section 5). The keyword file contains all the controls for the Prognosis Model except for the harvest controls. These are not specified as keywords but instead are copied directly into Prognosis by using the OPADD routine described below. The treelist file contains the initial stand inventory. Because MAIN contains a loop that allows more than one optimization to be done in a given run, units 2 and 5 must be rewound for each optimization.

The driver program for the Prognosis Model is split into three subprograms: PMAIN1, PMAIN2, and PMAIN3. The first subprogram contains the Prognosis initialization routines, including file-open statements, and it is called first. The file-open routines are near the top of PMAIN1, and they are called only once (when *ISKIP=0*) during the program execution. The file-open routines are skipped for each subsequent call to PMAIN1 (*ISKIP=1*).

After calling PMAIN1 and when test variable *JSET*<0, all the Prognosis variables necessary to restart the simulation from that point are stored on a scratch file (unit 50) by calling BHPUT. This is done so that subsequent Prognosis calls during the coordinate search do not have to repeat PMAIN1. When *JSET*>0, *JSET* is the number of periods before the first harvest. In this case, the stand is grown *JSET* periods by calling PMAIN2. The resulting Prognosis variables are stored on the scratch file by calling BHPUT in PMAIN2. Again, this avoids repeating the initial projection before harvests can take place during the coordinate search. Think of the optimization as a search of a multibranched decision tree. The optimizer uses BHPUT (and BHGET, which reverses the process) to back down the decision tree only as far as necessary to reach another node or branch in its search for the highest point. (Our implementation of BHPUT and BHGET is high-graded from the Parallel Processing Extension of Crookston and Stage [1988].) Note that the optimizer would execute faster if we used BHPUT to store the status of Prognosis in dynamic memory rather than in a scratch file. Unfortunately, there is not enough memory available within the 640K limitation of MS-DOS to do this.

The third section of the original Prognosis driver, PMAIN3, contains calls to output routines. These are not called by the optimization program because they are not needed and would seriously slow down execution of the optimizer. If Prognosis output is desired for a particular optimal policy, the user simply runs the normal Prognosis program (rather than the optimizer) after inserting the appropriate THINDBH keywords (from the optimizer's output file) into the keyword file for Prognosis. This procedure is useful for another reason: if the yields from Prognosis match the yields found by the optimizer (as they well should), then everything is working properly, both with the programs and the user.

Following the segment of code that opens the Prognosis files, there is a small block of code that echoes the optimization control information to the output file. This is described in section 3.3.

Harvest controls are initialized in two steps. First, the harvest control for each diameter class, period, and species group is assigned the value that was previously read from the input file. Second, if random harvest controls are desired to begin the optimization, random numbers between 0 and 1 are computed for controls in periods when harvests are scheduled. The user chooses the random number seed in this process. The controls are stored in two arrays, *U1* and *U2*, which are identical at the start. Harvest controls with a value of 0.0 indicate that no harvesting will take place. During the optimization, *U1* is the current optimal regime, and *U2* is a candidate regime obtained with a coordinate search and passed to Prognosis for evaluation.

The present value of the initial regime *U1* is computed with four subroutine calls. First, the Prognosis variables stored on the scratch file are obtained with BHGET. Second, the harvest controls in *U1* are copied onto the

proper Prognosis variables using the OPADD routines contained in GKEY. The OPADD routines do the same thing as THINDBH keywords in the keyword file, except that they are dynamic and therefore eliminate the need to predetermine the thinning levels. This feature is clearly the key that allows the optimizer to unlock Prognosis. The arguments for OPADD include the period, the diameter class limits, the harvest control, and the species number. Third, PMAIN2 is called with *JSET*<0 so that the stand is projected for the full number of cycles (NUMCYCLE is specified in the keyword file). When a thinning is implemented in Prognosis, all tree records that fall into the specified diameter and species class have their tree factor (the number of trees per acre represented by the tree record) reduced by the proportion represented by the harvest control. Within PMAIN2, a subroutine called STATE is called in each period. This classifies tree records by diameter class and species group. Before-harvest trees per acre and volume per acre by diameter and species class are stored in arrays *X* and *V*, respectively. Finally, after the stand projection, present value is calculated by calling VALUE. For each merchantable diameter and species class, value is the product of total volume before cut *V*, discounted price per unit volume *P*, and the proportion of trees cut *U*. For each unmerchantable class, value is the product of total number of trees before cut *X*, discounted price per tree *P*, and the proportion of trees cut *U*.

7.2 Search Process

Each iteration of the Method of Hooke and Jeeves involves a set of coordinate searches followed by an evaluation of the termination criteria and one pattern search. A coordinate search involves varying one control variable by a small amount and evaluating the new management regime. If the new management regime has a higher present value, the changed control variable is accepted and the next control variable is varied. The sequence of searches starts with the first cutting period and the smallest diameter class. Note that if the class does not contain trees, no search and evaluation takes place. Searches may go in both positive and negative directions, depending on the initial value of the harvest control. The present value of a candidate regime is computed using the same sequence of subroutine calls (BHGET, GKEY, PMAIN2, and VALUE), with *JSET*<0.

After coordinate searches have been performed for the control variables in the first harvest period, the state variables *X* must be restored to the values associated with the current optimum *U2*. This is done using BHGET, GKEY, and PMAIN2 with *JSET*<0. In addition, the stand is grown to the beginning of the next cutting period and saved. In this block, *JSET* is the number of periods before the second cut. In GKEY, only the harvest controls associated with the current cut are copied to Prognosis variables. PMAIN2 is called to grow the stand, and *JSET* is reset to –1 (in PMAIN2). The Prognosis variables are saved on the scratch file using BHPUT. The coordinate searches for the second growth period now proceed. Note that the evaluation of a control variable change in the second harvest period involves a Prognosis projection that starts with the updated stand at the beginning of that period. This avoids redundant growth projection in periods before the control variable takes effect.

After coordinate searches have been performed for all control variables, the termination criteria are evaluated. If the difference *DIF* in present value between two subsequent management regimes is less than a tolerance *EPS1*, and if the search distance *DELTA* is less than a tolerance *EPS*, then the search process stops and the current regime is printed. Otherwise, a pattern search is conducted.

The first step in the pattern search is to compute the search direction. The direction is *U2-U1*, which is the difference between management regimes before and after the most recent set of coordinate searches. Next, the status of relevant variables in Prognosis must be stored and then reinitialized because we want to start the projection from year 0. (Recall that after the last coordinate search, the stored stand equals the stand just prior to the last cut.) Then, the new management regime is computed by calling CONTROL. The pattern search changes the current regime by moving in the pattern search direction *DIR* by a distance *ALPHA*. The present value of this new regime is computed using BHGET, GKEY, PMAIN2, and VALUE, with *JSET*<0. If the new regime is an improvement, it is saved, the step size for the coordinate search *DELTA* is reduced, and the next set of coordinate searches is started. If the new regime is not better, the old regime is restored, the step size reduced, and the next set of searches started.

8 CREATING AN EXECUTABLE PROGRAM

To give users the option to change the Prognosis Optimization Program to suit their purposes, we have enclosed its source code on the distribution diskette. The source code is long and contains over a hundred subprograms, including all those for the Prognosis Model. Thus, it takes between 1 and 2 hours to create the executable program (most of this time is required to compile the source code). As Wykoff (1988) describes in the appendix of the Prognosis Model Update, there are three steps involved in creating an executable version of the Prognosis Model: (1) compiling the Fortran files, (2) creating object libraries, and (3) linking the object libraries and files. We use the same steps to create the executable version of the Prognosis Optimization Model.

8.1 Compiling Source Code

To compile the Prognosis code, begin by copying files *SOURCE1.ARC*, *SOURCE2.ARC*, and *SOURCE3.ARC* from the program diskette into the directory reserved for the optimizer. *SOURCE1.ARC* and *SOURCE2.ARC* contain the source code for version 5.2 of the Prognosis Model. *SOURCE3.ARC* contains the source code for the optimizer and several utility files for building the executable program. *SOURCE3.ARC* also contains four files that intentionally have the same names as files in

SOURCE1.ARC and *SOURCE2.ARC*: *MAIN.FOR*, *BLKDAT.FOR*, *OPFIND.FOR*, and *OPCOM.F77*. These files replace certain common blocks, arrays, and variable declarations that determine the number of keywords that may be used in Prognosis. These limits have been increased to accommodate the large number of THINDBH keywords necessary for optimization. When you extract each of these four files from *SOURCE3.ARC*, the ARC utility will stop and ask if you really want to write over a file that already exists; the correct answer is "yes". To extract all the remaining files, simply execute the *UNLOAD.BAT* file:

UNLOAD

MAIN.FOR contains the MAIN program for the optimizer and replaces the Prognosis main driver *MAIN.FOR* extracted above. The *PMAIN.FOR* file contains subroutines PMAIN1, PMAIN2, and PMAIN3, which together form the Prognosis main driver used in the optimization. Note that almost all of the calls to Prognosis output routines have been disabled in PMAIN3. File *OPT.FOR* contains optimizer subroutines OUT, GKEY, CONTROL, STATE, VALUE, and DRAND. The *BHSTAR.FOR* file contains 12 subroutines adapted from Crookston and Stage (1988) that allow for storing and retrieving the complete status of Prognosis variables and arrays during the course of a projection.

Your optimization directory now contains several hundred Fortran source files (**.FOR*) and common blocks (**.F77*), in addition to the utilities. That number is about to double because compilation will create an **.OBJ* file for each **.FOR* file. We have compiled successfully using Ryan-McFarland version 2.40 (RMFORT). (Wykoff [personal communication 1990] has also produced a working executable module of Prognosis using Lahey F77L version 4.01.) Note that changes in array dimensions contained in *BLKDAT.FOR, OPFIND.FOR*, and *OPCOM.F77* necessitate recompiling the Prognosis routines even if you already have a compiled version of Prognosis. Compile the source code by executing the *COMPILE.BAT* batch file and specifying the appropriate compiler as an argument (we use RMFORT):

COMPILE RMFORT

A relatively long time is needed to compile such a large number of subprograms (approximately 45 minutes on a 20-Mhz personal computer). Note that these programs are all compiled with the /IZ option, which is necessary to make the executable program small enough to run on a microcomputer under the 640K limit imposed by MS-DOS. Also note that the batch commands intentionally do not compile subprograms associated with the COVER extension (Moeur 1985) because they are not needed for unconstrained value optimization. However, an optimization problem that includes constraints on hiding cover for big game, for example, would require them. In that case the only alternatives would be either to recompile Prognosis with smaller dimensions for the tree vectors or to use an operating system such as UNIX that does not have the 640K restriction.

8.2 Building Object Libraries

If you now look at a directory listing, you run the risk of being overwhelmed by the sheer number of files that have been created. Clearly, some sort of file reduction is needed. Object libraries are the answer. By using the Phoenix PLINK86 overlay linker and associated libraries (supplied with the Ryan-McFarland RMFORT compiler), all of the object files needed for the optimizer are loaded into six object libraries: *MAIN.LIB, BASE.LIB, GROWTH.LIB, INPUT.LIB, INPUT2.LIB*, and *ESTAB.LIB*. Execute *LOADPLIB.BAT* to create these libraries:

LOADPLIB ALL

Note that you can also use *LOADPLIB.BAT* to build these libraries one at a time if you replace *ALL* with the appropriate library name in the preceding statement.

All of the source and object files can now be erased. Although this step may seem scary, all of the object files are conveniently stored in one of the six object libraries and all of the source code is still abstracted in the ARC files. Thus, the following commands should considerably reduce bookkeeping problems in your optimization directory:

*ERASE *.OBJ*
*ERASE *.FOR*
*ERASE *.F77*

As strange as it may seem, all of these erased files are still cluttering up your subdirectory, even though they do not appear to be in your directory. They have been marked as deleted in the file allocation table, but the file contents are untouched. The optimizer can be seriously slowed down in such a cluttered directory because it must repeatedly swap overlay segments when it is executed. The simplest solution is to create a new optimization directory, copy everything into it, and delete the old directory. Alternately, you could create a separate run directory containing only the executable optimizer code (including overlays), input and output files, response files, and any batch files that will simplify the submission of runs.

8.3 Linking the Object Code

The size of the optimization code requires the use of program overlays in the executable module. To link the object code and create the overlays, the Phoenix PLINK86 overlay linker is used. Batch file *OPTPLK.BAT* and response file *OPTPLK.RSP* contain the instructions for creating the overlaid version of the executable module. Execute the batch file with the command:

OPTPLK

The resulting executable module, *OPTGROW.EXE*, should require about 529K. The three overlays are *ESESTAB.OVL, ESGROWTH.OVL*, and *ESINPUT.OVL*.

8.4 Modifying the Program

If it is necessary to modify the optimizer code for some reason (such as increasing variable dimensions), then only a few steps are required to produce an executable module. After revising the appropriate source code, compile by specifying the program name and the /IZ option as arguments to the compiler. For example, assume that the subprogram STATE has been changed. Create a new *OPT.OBJ* file (where STATE is stored) by executing the Ryan-McFarland compiler:

RMFORT OPT/IZ

Next, update the appropriate object library (*MAIN.LIB* in this case) by using the *MODLOAD.BAT* batch file:

MODLOAD MAIN OPT

Finally, update the executable module *OPTGROW.EXE* by relinking:

OPTPLK

You will also need to update the ARC source file if you plan to work from the archive in the future:

ARC U SOURCE3 STATE.FOR

The other useful ARC options are D to delete a file and V to get a verbose listing of the contents of the archive file. The syntax is the same as for the X and U options that have been illustrated.

9 REFERENCES

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10 APPENDIX: OPTIMIZER PROGRAM CODE

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      PROGRAM MAIN

C     OPTIMIZE PROGNOSIS USING THE COORDINATE GRID SEARCH METHOD
C     OF HOOK AND JEEVES.

C     WRITTEN BY ROBERT G. HAIGHT 1988 AND MODIFIED IN 1989 BY
C     ROBERT A. MONSERUD  (PROGRAMMING DIVISION OF "THE BOBS")

C     OPTIMIZATION PROBLEM BOUNDS:
C       MAXIMUM NUMBER OF PROGNOSIS GROWTH PERIODS = 33
C       MAXIMUM NUMBER OF DIAMETER CLASSED         =  8
C       MAXIMUM NUMBER OF SPECIES GROUPS           =  3
C     IF THESE DIMENSIONS ARE CHANGED, BE SURE TO MODIFY AND RECOMPILE
C     SUBROUTINES CONTROL, OUT, STATE, VALUE, GKEY, AND PMAIN2.

      COMMON/BEST/DCL(8,2),D(8),U1(33,8,3),U2(33,8,3),DIR(33,8,3),
     >IYEAR(33),X(33,8,3),V(33,8,3),P(33,8,3),BF(33),VA(33),NS(3),
     >SP(3,10),ICUT(33),NCYCLE,NCLASS,NGROUP,MVOL

      DIMENSION C(33,8,3),DCB(9),ISP(10)
      DOUBLE PRECISION DRAND,SEED(20),RAND

      OPEN(25,FILE='BOBS2.INP',STATUS='UNKNOWN',ACCESS='SEQUENTIAL')
      OPEN(26,FILE='BOBS2.OUT',STATUS='UNKNOWN',ACCESS='SEQUENTIAL')
      OPEN(UNIT=50,STATUS='SCRATCH',FORM='UNFORMATTED')

      ISKIP = 0

C**********************************************************************
C     BEGIN INPUT AND INITIALIZATION PHASE
C**********************************************************************

C*****READ NUMBER OF RUNS AND RANDOM # SEEDS
      READ(25,259) NRUN,(SEED(NR),NR = 1,NRUN)
259   FORMAT(I5,20D5.0)

C*****READ OPTIMIZER CONTROL PARAMETERS
      READ(25,257) R,ALPHA,DELTA1,EPS,EPS1
257   FORMAT(20F5.0)
      MAXVOL=0
      IF(R.LT.0.0001) MAXVOL=1

C*****READ INTERNAL PARAMETERS
C     NCYCLE = 1 + NUMBER OF PROGNOSIS CYCLES                    (TIME)
C     MERCH = INDEX FOR THE FIRST MERCHANTABLE DIAMETER CLASS
C     NGROUP = NUMBER OF SPECIES GROUPS FOR VALUE CLASSIFICATION  (SPP)
C     MVOL > 0 IF BOARD FT VOL; MVOL < 0 IF MERCH CUFT VOL
C     LENGTH = LENGTH OF THE GROWTH PERIOD (TIMEINT)
C     NTH = PRINT EVERY NTH PROGNOSIS CYCLES
C     NOKEYW = 0 IF YOU WANT NO THINDBH KEYWORD OUTPUT WRITTEN

      READ(25,258) NUMCYC,MERCH,NGROUP,MVOL,LENGTH,NTH,NOKEY
258   FORMAT(10I5)
      NCYCLE = NUMCYC + 1
      MERCH1 = MERCH - 1
      YEARS = FLOAT( NUMCYC * LENGTH )
      IF(NTH.EQ.0) NTH = 1

C*****READ CUTTING PERIODS
C     NCUTS = NUMBER OF CUTTING PERIODS
      READ(25,258) NCUTS,(ICUT(I),I = 1,NCUTS)
C     JS = NUMBER OF PERIODS BEFORE THE FIRST CUTTING
      JS = ICUT(1) - 1
      IF(JS.EQ.0) JS = -1
      JSET = JS

C*****READ THE NCLASS+1 DIAMETER CLASS BOUNDARYS
      READ(25,255) NCP1,(DCB(K),K = 1,NCP1)
255   FORMAT(I5,20F5.0)
C     NCLASS = NUMBER OF DIAMETER CLASSES                        (SIZE)
      NCLASS = NCP1 - 1
      DO 15 K = 1,NCLASS
       DCL(K,1) = DCB(K)
       DCL(K,2) = DCB(K+1)
       D(K) =  (DCB(K) + DCB(K+1)) /2.
15    CONTINUE

C*****FOR THE NGROUP SPECIES GROUPS READ THE SPECIES ID NUMBERS
      DO 13 L = 1,NGROUP
        READ(25,255) NSP, (SP(L,L1),L1=1,NSP)
        NS(L) = NSP
13    CONTINUE

C*****READ AND COMPUTE DISCOUNTED STUMPAGE PRICES
      DO 12 L = 1,NGROUP
      READ(25,257) (P(1,J,L),J = 1,NCLASS)
      DO 10 I = 1,NCYCLE
        DIS = (1.+R) ** ((I - 1)*LENGTH)
        DO 11 J = 1,NCLASS
          P(I,J,L) = P(1,J,L)/DIS
11      CONTINUE
10    CONTINUE
12    CONTINUE

C*****READ THINNING CONTROL VARIABLES (PERCENTAGE OF TREES REMOVED)
C     OUTER LOOP FOR SPP GROUPS,
C     INNER LOOP FOR TIME           (DOWN),
C     IMPLIED LOOP FOR DIA CLASSES (ACROSS)
      DO 39 L = 1,NGROUP
       DO 36 I = 1,NUMCYC
        READ (25,256) (C(I,K,L),K = 1,NCLASS)
256     FORMAT(10F7.4)
36     CONTINUE
        DO 38 K = 1,NCLASS
        C(NCYCLE,K,L) = 1.0
38    CONTINUE
39    CONTINUE

C**********************************************************************
C     OUTER LOOP FOR SEPERATE OPTIMIZATIONS WITH DIFFERENT SEEDS
C**********************************************************************

      DO 999 NR = 1,NRUN

      NCALLS = 0
      DELTA = DELTA1

C*****CALL PROGNOSIS TO OPEN TREELIST FILE 2 AND KEYWORD FILE 5
      REWIND 2
      REWIND 5
      CALL PMAIN1(ISKIP)
      IF (JSET.LT.0) THEN
        CALL BHPUT
      ELSE
        CALL PMAIN2(JSET)
      ENDIF

C*****PRINT INPUT
      WRITE (26,648)
648   FORMAT(///'BOBS2: PROGNOSIS OPTIMIZATION BY THE BOBS')
      SEED1 = SNGL(SEED(NR))
```

```
      WRITE(26,649) NR,R,ALPHA,DELTA,EPS,EPS1,SEED1
649   FORMAT(/,
     >'OPTIMIZATION NUMBER  ',I4/,
     >'INTEREST RATE =      ',F8.3/,
     >'ACCELERATION STEP =  ',F8.3/,
     >'BEGINNING STEP SIZE =',F8.3/,
     >'MINIMUM STEP SIZE =  ',F8.3/,
     >'MINIMUM GAIN =       ',F8.3/,
     >'RANDOM NUMBER SEED = ',F8.3/)

      IF(NCUTS.GT.1) WRITE(26,658) NCUTS,(ICUT(K),K = 1,NCUTS)
658   FORMAT('THE OPTIMIZER WILL DETERMINE',I3,' HARVESTS.'/
     >'THEY OCCUR IN PERIODS:',20I4
     >/22X,13I4)
      IF(NCUTS.EQ.1) WRITE(26,659) ICUT(1)
659   FORMAT('THE OPTIMIZER WILL DETERMINE 1 HARVEST,',
     >' OCCURRING IN PERIOD',I3)
      WRITE(26,651)
651   FORMAT('  ')
      DO 30 L = 1,NGROUP
        WRITE(26,650) L,(SP(L,L1),L1 = 1,NS(L))
650     FORMAT('SPECIES CODES FOR GROUP',I2,' ARE',10F4.0)
30    CONTINUE
      WRITE(26,652)
652   FORMAT(/'HOOKE & JEEVES COORDINATE SEARCH PROCESS: '/)

C***********************************************************************
C     BEGIN SEARCH PROCESS
C***********************************************************************

C*****FOR EACH SPECIES GROUP
      DO 31 L = 1,NGROUP

C*****SET CONTROL VARIABLES
      DO 33 I = 1,NCYCLE
       DO 32 K = 1,NCLASS
         U1(I,K,L) = C(I,K,L)
32     CONTINUE
33    CONTINUE

C*****SET RANDOM STARTING VALUES
      IF(SEED(NR).GE.0.D0) THEN
      DO 26 I1 = 1,NCUTS
        I = ICUT(I1)
        DO 27 K = 1,NCLASS
          RAND = DRAND(SEED(NR))
          U1(I,K,L) = SNGL(RAND)
27      CONTINUE
26    CONTINUE
      ENDIF

C*****SET U2(I,K,L) = U1(I,K,L)
       DO 28 I = 1,NCYCLE
        DO 29 K = 1,NCLASS
          U2(I,K,L) = U1(I,K,L)
          X(I,K,L) = 0.
29      CONTINUE
28     CONTINUE
31    CONTINUE

C*****COMPUTE PRESENT VALUE OF U1
      CALL BHGET
      CALL GKEY(DCL,U1,NCLASS,NGROUP,NS,SP,ICUT,NCUTS,1,LENGTH)
      CALL PMAIN2(JSET)
      CALL VALUE(Z1,P,V,X,U1,NCYCLE,NCLASS,MERCH,NGROUP)
      Z2 = Z1
      NCALLS = NCALLS + 1
      WRITE(26,635) Z1
635   FORMAT('PRESENT VALUE =',F10.2)

C*****FOR EACH CUTTING PERIOD I
49    CONTINUE
      DO 46 I1 = 1,NCUTS
        I = ICUT(I1)

C*****FOR EACH DIAMETER AND SPECIES CLASS J AND L
       DO 47 J = 1,NCLASS
        DO 48 L = 1,NGROUP

C*****ADD DELTA TO TEST CONTROL U2(I,J,L)
         IF(X(I,J,L).LT..01) GOTO 48
         IF(U1(I,J,L).EQ.1.) GOTO 43
         U2(I,J,L) = U1(I,J,L) + DELTA
         IF(U2(I,J,L).GT.1.) U2(I,J,L) = 1.

C*****GET THE INITIAL STAND AND COMPUTE PV OF CHANGED CONTROL
         CALL BHGET
         CALL GKEY(DCL,U2,NCLASS,NGROUP,NS,SP,ICUT,NCUTS,I1,LENGTH)
         CALL PMAIN2(JSET)
         CALL VALUE(Z,P,V,X,U2,NCYCLE,NCLASS,MERCH,NGROUP)
         NCALLS = NCALLS + 1
         IF(Z.GT.Z2) GOTO 40

C*****IF PLUS DELTA DOES NOT IMPROVE PV, SUBTRACT DELTA TO TEST CONTROL
         IF(U1(I,J,L).EQ.0.) GOTO 42
43       CONTINUE
         U2(I,J,L) = U1(I,J,L) - DELTA
         IF(U2(I,J,L).LT.0.) U2(I,J,L) = 0.

C*****GET THE INITIAL STAND AND COMPUTE PV OF CHANGED CONTROL
         CALL BHGET
         CALL GKEY(DCL,U2,NCLASS,NGROUP,NS,SP,ICUT,NCUTS,I1,LENGTH)
         CALL PMAIN2(JSET)
         CALL VALUE(Z,P,V,X,U2,NCYCLE,NCLASS,MERCH,NGROUP)
         NCALLS = NCALLS + 1
         IF (Z.GT.Z2) GOTO 40
42       CONTINUE
         U2(I,J,L) = U1(I,J,L)
         Z = Z2
40       CONTINUE
         Z2 = Z
48      CONTINUE
47     CONTINUE

C*****RECOMPUTE STATE USING BEST CONTROL SEQUENCE
       CALL BHGET
       CALL GKEY(DCL,U2,NCLASS,NGROUP,NS,SP,ICUT,NCUTS,I1,LENGTH)
       CALL PMAIN2(JSET)
       NCALLS = NCALLS + 1

C*****PARK THE STAND AFTER I1 CUTS
       IF(I1.LT.NCUTS) THEN
        JSET = ICUT(I1 + 1) - 1
        CALL BHGET
        CALL GKEY(DCL,U2,NCLASS,NGROUP,NS,SP,ICUT,I1,I1,LENGTH)
        CALL PMAIN2(JSET)
        NCALLS = NCALLS + 1
       ENDIF
46    CONTINUE

C*****NOTE TERMINATION OF STEP SEARCH LOOP
      WRITE(26,637) DELTA
```

```
637   FORMAT(' PERFORMED STEP SEARCH WITH DELTA =  ',F5.3)
      WRITE(26,635) Z2

C*****IF DIF .LT. EPS1 .AND. DELTA. .LT. EPS, GO TO PRINT
        DIF = Z2 - Z1
        IF(DIF.LT.EPS1.AND.DELTA.LT.EPS) GOTO 90

C*****PERFORM ACCELERATION STEP: FIRST DETERMINE SEARCH DIRECTION
        DO 50 I1 = 1,NCUTS
         I = ICUT(I1)
         DO 52 L = 1,NGROUP
          DO 51 J = 1,NCLASS
            DIR(I,J,L) = U2(I,J,L) - U1(I,J,L)
            U1(I,J,L) = U2(I,J,L)
51        CONTINUE
52       CONTINUE
50      CONTINUE

C*****NEXT, REINITIALIZE AND PUT THE STAND
      REWIND 2
      REWIND 5
      JSET = JS
      CALL PMAIN1(ISKIP)
      IF(JSET.LT.0) THEN
        CALL BHPUT
      ELSE
        CALL PMAIN2(JSET)
      ENDIF

C*****NEXT, COMPUTE PRESENT VALUE
          Z1 = Z2
          CALL CONTROL(ALPHA,U2,DIR,NCLASS,NGROUP,ICUT,NCUTS)
          CALL BHGET
          CALL GKEY(DCL,U2,NCLASS,NGROUP,NS,SP,ICUT,NCUTS,1,LENGTH)
          CALL PMAIN2(JSET)
          CALL VALUE(Z2,P,V,X,U2,NCYCLE,NCLASS,MERCH,NGROUP)
        NCALLS = NCALLS + 1

C*****IF IMPROVEMENT, SAVE AND RETURN TO COORDINATE SEARCH
        IF(Z2.GT.Z1) THEN
        WRITE(26,636)
636     FORMAT('  ACCELERATION STEP SUCCESSFUL')
        WRITE(26,635) Z2
        DO 54 I1 = 1,NCUTS
         I = ICUT(I1)
         DO 57 L = 1,NGROUP
          DO 55 J = 1,NCLASS
            U1(I,J,L) = U2(I,J,L)
55        CONTINUE
57       CONTINUE
54      CONTINUE
        Z1 = Z2
        IF(DELTA.GT.EPS) DELTA = DELTA/2.
        GOTO 49

C*****IF NO IMPROVEMENT, REDUCE STEP SIZE AND RETURN TO COORDINATE
        ELSE
        WRITE(26,656)
656     FORMAT('  ACCELERATION STEP NOT SUCCESSFUL')
        DO 70 I1 = 1,NCUTS
         I = ICUT(I1)
         DO 72 L = 1,NGROUP
          DO 71 J = 1,NCLASS
            U2(I,J,L) = U1(I,J,L)
71        CONTINUE
72       CONTINUE
70      CONTINUE
        Z2 = Z1
        IF(DELTA.GT.EPS) DELTA = DELTA/2.
        GOTO 49
        ENDIF

90    CONTINUE

C*********************************************************************
C     SEARCH PROCESS COMPLETE; PRINT RESULTS
C*********************************************************************

C*****COMPUTE AND SUBTRACT INITIAL VALUE (OR VOLUME)

      VAINIT = 0.
      DO 80 L = 1,NGROUP
        DO 86 J = 1,MERCH1
          VAINIT = VAINIT + P(1,J,L) * X(1,J,L)
86      CONTINUE
        DO 89 J = MERCH,NCLASS
          VAINIT = VAINIT + P(1,J,L) * V(1,J,L)
89      CONTINUE
80    CONTINUE
      Z2NET = Z2 - VAINIT

C*****PRINT OPTIMAL VALUE

      IF(MAXVOL.EQ.0) WRITE(26,626) NCALLS,VAINIT,Z2NET
626   FORMAT(/'NUMBER OF PROGNOSIS SIMULATIONS =',I5//
     >'INITIAL VALUE = ',F10.2,' DOLLARS/AC'//
     >'OPTIMAL PRESENT NET VALUE (PNV) =',F10.2,' DOLLARS/AC'/ )

      VAINIT = VAINIT * 1000.
      Z2NET = Z2NET * 1000.
      AAP = Z2NET / YEARS

      IF(MAXVOL.EQ.1.AND.MVOL.GT.0)WRITE(26,627) NCALLS,VAINIT,Z2NET,AAP
627   FORMAT(/'NUMBER OF PROGNOSIS SIMULATIONS =',I5//
     >'INITIAL VOLUME =     ',F14.1,' BDFT/AC'//
     >'NET OPTIMAL VOLUME =',F14.1,' BDFT/AC'//
     >'AVERAGE ANNUAL PRODUCTION =',F7.1,' BDFT/AC/YR'/)

      IF(MAXVOL.EQ.1.AND.MVOL.LE.0)WRITE(26,628) NCALLS,VAINIT,Z2NET,AAP
628   FORMAT(/'NUMBER OF PROGNOSIS SIMULATIONS =',I5//
     >'INITIAL VOLUME =     ',F14.1,' CUFT/AC'//
     >'NET OPTIMAL VOLUME =',F14.1,' CUFT/AC'//
     >'AVERAGE ANNUAL PRODUCTION =',F7.1,' CUFT/AC/YR'/)

C*****COMPUTE OUTPUT YEAR ARRAY
      DO 66 I = 1,NCYCLE
        IYEAR(I) = (I - 1) * LENGTH
66    CONTINUE

C*****WRITE RESIDUAL STATE SEQUENCE
      DO 60 L = 1,NGROUP
      DO 58 I = 1,NCYCLE
        VA(I) = 0.
        BF(I) = 0.
        DO 56 J = 1,MERCH1
          U1(I,J,L) = X(I,J,L) * (1. - U2(I,J,L))
          VA(I) = VA(I) + P(1,J,L) * U1(I,J,L)
56      CONTINUE
        DO 59 J = MERCH,NCLASS
          U1(I,J,L) = X(I,J,L) * (1. - U2(I,J,L))
          VA(I) = VA(I) + P(1,J,L) * V(I,J,L) * (1. - U2(I,J,L))
          BF(I) = BF(I) + V(I,J,L) * (1. - U2(I,J,L))
```

```
59        CONTINUE
58      CONTINUE
        WRITE(26,657) L
657     FORMAT(/,'RESIDUAL TREES PER ACRE FOR SPECIES GROUP',I3)
        CALL OUT(IYEAR,D,U1,BF,VA,NCYCLE,NCLASS,L,0,NTH)
60      CONTINUE

C*****WRITE HARVEST SEQUENCE
        DO 68 L = 1,NGROUP
        DO 61 I = 1,NCYCLE
          VA(I) = 0.
          BF(I) = 0.
          DO 67 J = 1,MERCH1
            U1(I,J,L) = X(I,J,L) * U2(I,J,L)
            VA(I) = VA(I) + P(1,J,L) * U1(I,J,L)
67        CONTINUE
          DO 62 J = MERCH,NCLASS
            U1(I,J,L) = X(I,J,L) * U2(I,J,L)
            VA(I) = VA(I) + P(1,J,L) * V(I,J,L) * U2(I,J,L)
            BF(I) = BF(I) + V(I,J,L) * U2(I,J,L)
62        CONTINUE
61      CONTINUE
        WRITE(26,660) L
660     FORMAT(/,'HARVESTED TREES PER ACRE FOR SPECIES GROUP',I3,':')
        CALL OUT(IYEAR,D,U1,BF,VA,NCYCLE,NCLASS,L,0,NTH)
68      CONTINUE

C*****WRITE CONTROL SEQUENCE
        DO 69 L = 1,NGROUP
        DO 63 I = 1,NCYCLE
          DO 64 J = 1,NCLASS
          IF(U1(I,J,L).GT.0.001)  U1(I,J,L)  =  U2(I,J,L) * 100.
64        CONTINUE
63      CONTINUE
        WRITE(26,633) L
633     FORMAT(/,'PERCENTAGE TREES PER ACRE CUT FOR SPECIES GROUP'
     >,I3,':')
        CALL OUT(IYEAR,D,U1,BF,VA,NCYCLE,NCLASS,L,1,NTH)
69      CONTINUE


C*****REWRITE CONTROL SEQUENCE IN THE INPUT FORMAT
C       (DIAMETER CLASSES ACROSS, TIME PERIODS DOWN)
        DO 85 L = 1,NGROUP
        DO 83 I = 1,NCYCLE
          DO 84 J = 1,NCLASS
            U1(I,J,L)  =  U1(I,J,L) / 100.
84        CONTINUE
83      CONTINUE

        WRITE(26,670) L
670     FORMAT(/,'OPTIMAL HARVEST CONTROL PARAMETERS FOR SPECIES GROUP'
     >,I3,':')
          DO 87 I = 1,NUMCYC
          WRITE(26,256) (U1(I,J,L),J = 1,NCLASS)
87      CONTINUE

85      CONTINUE

        IF(NOKEY.EQ.0) GOTO 990
C*****WRITE CONTROL SEQUENCE AS THINDBH KEYWORDS FOR PROGNOSIS
        WRITE(26,690)
690     FORMAT(/,'OPTIMAL HARVEST KEYWORDS FOR PROGNOSIS'/
     >' (INSERT IN THE KEYWORD FILE)' )

        DO 94 I = 1,NCUTS
        K = ICUT(I)
        YEAR = (LENGTH * (K - 1)) + 1
         DO 93 J = 1,NCLASS
          J1 = J + 1
          DO 92 L = 1,NGROUP
           IF(U1(K,J,L).LT.0.0001) GOTO 92
           NSP= NS(L)
            DO 91 L1=1,NSP
             SPECIE = SP(L,L1)
             IF(NGROUP.GT.1) THEN
              WRITE(26,696) YEAR,DCB(J),DCB(J1),U1(K,J,L),SPECIE
696           FORMAT('THINDBH    ',3F10.0,F10.4,F10.0 )
             ELSE
              WRITE(26,696) YEAR,DCB(J),DCB(J1),U1(K,J,L)
             ENDIF
91          CONTINUE
92        CONTINUE
93       CONTINUE
94      CONTINUE

990     CONTINUE
999     CONTINUE
        ENDFILE 26
        END

C*******************************************************************
C*******************************************************************

        SUBROUTINE OUT(IYEAR,D,U,BF,VA,NCYCLE,NCLASS,L,L3,NTH)
        DIMENSION IYEAR(33),D(8),U(33,8,3),BF(33),VA(33),TR(33),BA(33)

C*****COMPUTE STAND AVERAGES
        C = 0.00545415
        DO 10 I = 1,NCYCLE
          TR(I) = 0.
          BA(I) = 0.
          DO 11 J = 1,NCLASS
            TR(I) = TR(I) + U(I,J,L)
            BA(I) = BA(I) + U(I,J,L) * C * D(J)**2
11        CONTINUE
10      CONTINUE

C*****WRITE STAND STATISTICS

        N1 = 1
        N2 = NCYCLE
        NPAGE = 1
        N3=(NCYCLE-1)/NTH  + 1
        IF(N3.GT.17) NPAGE = 2
        IF(NPAGE.GT.1) N2 = 17 * NTH

        DO 100 IPAGE = 1,NPAGE
        IF(IPAGE.EQ.2) N1 = N2 + 1
        IF(IPAGE.EQ.2) N2 = NCYCLE

        WRITE(26,401)
401       FORMAT(/,' DBH       --------YEAR------->')
        WRITE(26,402) (IYEAR(I),I = N1,N2,NTH )
402       FORMAT('CLASS',1X,17(2X,I3,2X))
        IF(L3.GT.0) GOTO 80
        DO 40 J = 1,NCLASS
          WRITE(26,403) D(J),(U(I,J,L),I = N1,N2,NTH)
403       FORMAT(F4.0,1X,17F7.1)
40      CONTINUE
```

```
      WRITE(26,412) (TR(I),I = N1,N2,NTH)
412    FORMAT('TOTAL',17F7.0)
      WRITE(26,413) (BA(I),I = N1,N2,NTH)
413    FORMAT('BA/AC',17F7.0)
      WRITE(26,407) (BF(I),I = N1,N2,NTH)
407     FORMAT('VO/AC',17F7.2)
      WRITE(26,414) (VA(I),I = N1,N2,NTH)
414    FORMAT('$$/AC',17F7.1)
      GOTO 100

80    CONTINUE
      DO 90 J = 1,NCLASS
        WRITE(26,404) D(J),(U(I,J,L),I = N1,N2,NTH)
404     FORMAT(F4.0,1X,17F7.2)
90    CONTINUE

100   CONTINUE
      RETURN
      END

C**********************************************************************
C**********************************************************************

      SUBROUTINE CONTROL(THETA,U2,DIR,NCLASS,NGROUP,ICUT,NCUTS)
      DIMENSION U2(33,8,3),DIR(33,8,3),ICUT(33)


      DO 15 I1 = 1,NCUTS
       I = ICUT(I1)
       DO 14 L = 1,NGROUP
        DO 16 K = 1,NCLASS
          U2(I,K,L) = U2(I,K,L) + THETA * DIR(I,K,L)
          IF(U2(I,K,L).LT.0.) U2(I,K,L) = 0.
          IF(U2(I,K,L).GT.1.) U2(I,K,L) = 1.
16      CONTINUE
14     CONTINUE
15    CONTINUE
      RETURN
      END

C**********************************************************************
C**********************************************************************

      SUBROUTINE VALUE(Z,P,V,X,U,NCYCLE,NCLASS,MERCH,NGROUP)
      DIMENSION P(33,8,3),V(33,8,3),X(33,8,3),U(33,8,3)

C*****COMPUTE PRECOMMERCIAL AND COMMERCIAL THINNING REVENUES
C*****FOR EACH TIME PERIOD

      MERCH1=MERCH-1
      Z=0.
      DO 21 I=1,NCYCLE
       DO 24 L=1,NGROUP
        DO 22 J=1,MERCH1
          Z=Z+P(I,J,L)*X(I,J,L)*U(I,J,L)
22      CONTINUE
        DO 23 J=MERCH,NCLASS
          Z=Z+P(I,J,L)*V(I,J,L)*U(I,J,L)
23      CONTINUE
24     CONTINUE
21    CONTINUE
      RETURN
      END
```

```
C**********************************************************************
C**********************************************************************

      SUBROUTINE GKEY(DCL,U,NCLASS,NGROUP,NS,SP,ICUTS,NCUTS,NC1,LENGTH)
      DIMENSION DCL(8,2),U(33,8,3),NS(3),SP(3,10),ICUTS(33),
     >WK6(4)

C*****REWIND PROGNOSIS INPUT AND OUTPUT FILES
C*****TREE DATA FILE
      REWIND 2
C*****TREE LIST OUTPUT FILE
      REWIND 3
C*****SUMMARY OUTPUT FILE
      REWIND 4
C*****OUTPUT FILE
      REWIND 6

C*****FOR EACH CUT CYCLE WRITE THINDBH KEYWORDS USING OPADD ROUTINE
      DO 40 I1=NC1,NCUTS
        I=ICUTS(I1)
        IYR=(I-1)*LENGTH+1
        DO 30 L=1,NGROUP
          NSP=NS(L)
          DO 20 L1=1,NSP
            DO 10 K=1,NCLASS
              WK6(1)=DCL(K,1)
              WK6(2)=DCL(K,2)
              WK6(3)=U(I,K,L)
              WK6(4)=SP(L,L1)
              CALL OPADD(IYR,228,4,WK6,KODE)
              IF(KODE.GT.0) STOP 'OPTION PROCESSING ERROR IN GKEY'
10          CONTINUE
20        CONTINUE
30      CONTINUE
40    CONTINUE

      RETURN
      END

C**********************************************************************
C**********************************************************************

      SUBROUTINE STATE

      COMMON/BEST/DCL(8,2),D(8),U1(33,8,3),U2(33,8,3),DIR(33,8,3),
     >IYEAR(33),X(33,8,3),V(33,8,3),P(33,8,3),BF(33),VA(33),NS(3),
     >SP(3,10),ICUT(33),NCYCLE,NCLASS,NGROUP,MVOL

      INCLUDE 'ARRAYS.F77'
      INCLUDE 'CONTRL.F77'
      INCLUDE 'PLOT.F77'

      I=ICYC+1

C*****SET X(I,J,L)=0.
      DO 10 L=1,NGROUP
        DO 5 J=1,NCLASS
          X(I,J,L)=0.
          V(I,J,L)=0.
5       CONTINUE
10    CONTINUE
```

```
C*****FOR EACH RECORD READ SPECIES, TPA, DBH AND VOLUME
      DO 40 J1=1,ITRN
        SP1=ISP(J1)
        TPA=PROB(J1)/GROSPC
        BDBH=DBH(J1)
        IF(MVOL.GT.0) THEN
          TVOL=BFV(J1)
        ELSE
          TVOL=WK1(J1)
        ENDIF
        IF(SP(1,1).EQ.0.) SP1=0.

C*****DETERMINE DIAMETER CLASS
        DO 30 J=1,NCLASS
         IF(BDBH.LT.DCL(J,2)) THEN

C*****DETERMINE SPECIES CLASS AND UPDATE TPA AND VOLUME
           DO 22 L=1,NGROUP
            NSPB=NS(L)
            DO 20 L1=1,NSPB
             IF(SP1.EQ.SP(L,L1)) THEN
              X(I,J,L)=X(I,J,L)+TPA
              V(I,J,L)=V(I,J,L)+TVOL*TPA/1000.
              GOTO 40
             ENDIF
20          CONTINUE
22         CONTINUE
         ENDIF
30      CONTINUE
40    CONTINUE
      RETURN
      END
```

```
C**********************************************************************
C**********************************************************************

      DOUBLE PRECISION FUNCTION DRAND(IX)
      DOUBLE PRECISION A,P,IX,B15,B16,XHI,XALO,LEFTLO,FHI,K
      DATA A/16807.D0/,B15/32768.D0/,B16/65536.D0/,P/2147483647.D0/
      XHI = IX/B16
      XHI = XHI - DMOD(XHI,1.D0)
      XALO = (IX - XHI*B16)*A
      LEFTLO = XALO/B16
      LEFTLO = LEFTLO - DMOD(LEFTLO,1.D0)
      FHI = XHI*A + LEFTLO
      K = FHI/B15
      K = K - DMOD(K,1.D0)
      IX = (((XALO - LEFTLO*B16) - P) + (FHI - K*B15)*B16) + K
      IF(IX.LT.0.D0) IX = IX + P
      DRAND = IX*4.656612875D - 10
      RETURN
      END
```

Monserud, Robert A.; Haight, Robert G. 1990. A programmer's guide to the Prognosis Optimization Model. Gen. Tech. Rep. INT-269. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 24 p.

The Prognosis Optimization Model is used to compute optimal harvest regimes for mixed-conifer stands in the Northern Rocky Mountains. The optimizer is capable of determining optimal regimes (termed any-aged) without any constraints on the age structure or species composition of the stand. It also may be used to determine optimal thinning regimes for plantations or natural stands that are eventually clearcut. The input requirements and output for the optimization model are described in detail. Input and output for three optimization runs for maximizing the present value and merchantable cubic foot volume of a stand are described. Instructions for installing and running the program on a personal computer are provided. For those interested in changing the source code for the optimizer, the structure of the optimization code is described, and detailed instructions for compiling the program are provided.

KEYWORDS: optimal harvesting, any-aged management, single-tree simulator

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The Intermountain Research Station provides scientific knowledge and technology to improve management, protection, and use of the forests and rangelands of the Intermountain West. Research is designed to meet the needs of National Forest managers, Federal and State agencies, industry, academic institutions, public and private organizations, and individuals. Results of research are made available through publications, symposia, workshops, training sessions, and personal contacts.

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**Intermountain
Research Station**

General Technical
Report INT-270

June 1990

Proceedings—Symposium on Whitebark Pine Ecosystems: Ecology and Management of a High-Mountain Resource

Intermountain Research Station
324 25th Street
Ogden, UT 84401

Proceedings—Symposium on Whitebark Pine Ecosystems: Ecology and Management of a High-Mountain Resource

Bozeman, MT, March 29-31, 1989

Compilers:

Wyman C. Schmidt, Project Leader
Kathy J. McDonald, Clerk-Typist

Intermountain Research Station, Forest Service
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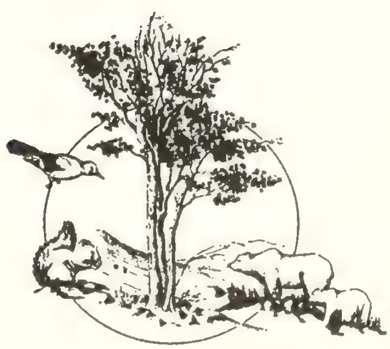

SAF 90-03

FOREWORD

"New Perspectives in Forestry" is a recently coined term that describes the need for holistic approaches to forest management practices. It recognizes the broad range of resources that must be accounted for in forest management activities. Forest managers have long recognized this need and have responded accordingly—to a lesser degree in forests where a single resource value predominates and to a greater degree in forests where the various resource values are about equal. However, in nearly every case, the knowledge base needed for holistic management is incomplete and not readily available to those who must make the tough management decisions. This has particularly been the case for those ecosystems whose resources have had little demand in the past but whose values are rapidly being recognized. Whitebark pine ecosystems fit that definition and were the subject of a preliminary workshop February 24, 1987, and of a major symposium March 29-31, 1989, at Montana State University, Bozeman. This proceedings is a product of the 1989 symposium "Whitebark Pine Ecosystems: Ecology and Management of a High-Mountain Resource."

This symposium explored the ecology and management of high-mountain ecosystems of western North America where whitebark pine and its associated flora and fauna predominate—a subject of rapidly emerging recognition and importance. This was the first symposium that examined in depth these fragile high-mountain areas so important for their total complement of resource values. Specific objectives of the symposium were to ferret out and present the best information available for these relatively unexplored forests—forests that harbor the grizzly bear, mountain sheep, and elk; that provide late-season water for the valleys below; that provide expansive views and solitude for the high-mountain visitor; and, to a lesser extent, provide some of the wood products for North America.

Some striking similarities to European and Asian ecosystems were pointed out, and we in North America can learn much from our colleagues who research and manage the ecosystems in Eurasia. While our high-elevation ecosystems in North America have seen little occupancy and use to date, those in Eurasia have a long history of use and abuse as pointed out by Drs. Ives, Holtmeier, Lanner, and Ross in their papers. Much of what is learned there will likely be applicable in North America.

Happily, far more information was available about whitebark pine ecosystems than we envisioned at the outset of planning for this symposium, and the 52 papers and 14 poster synopses document that fact. About 150 people attended all or part of the symposium and 25 went on the postsymposium field trip into whitebark pine forests at Big Sky, MT.

The symposium program consisted of five major sessions: (1) High-Mountain Resources of the World, (2) High-Mountain Resources of North America, (3) Ecology of Whitebark Pine Forests, (4) Management Implications, and (5) Where Do We Go From Here?

The symposium was sponsored by the Forest Service, U.S. Department of Agriculture; National Park Service, U.S. Department of the Interior; Montana State University; and the Society of American Foresters, with designation as a SAF Regional Technical Conference.

The symposium was planned by:

Co-Chairmen:

Wyman C. Schmidt, Project Leader and Research Silviculturist, Intermountain Research Station, Bozeman, MT

Richard Kracht, Forest Silviculturist, Gallatin National Forest, Bozeman, MT

Coordinators:

Steve Arno, Research Forester, Intermountain Research Station, Missoula, MT

Kathy Hansen-Bristow, Associate Professor of Geography and Earth Sciences, Montana State University, Bozeman, MT

Wendel Hann, Regional Ecologist, Northern Region, Forest Service, Missoula, MT

Dave Mattson, Wildlife Biologist, Interagency Grizzly Bear Team, Bozeman, MT

Melanie Stocks, Events and Promotion Specialist, Montana State University, Bozeman, MT

Tad Weaver, Plant Ecologist, Biology Department, Montana State University, Bozeman, MT

I want to acknowledge the planning committee members, and the organizations that supported them, for their imaginative, enthusiastic, and dedicated efforts in the planning and conduct of this symposium. Also, I wish to acknowledge Gina Gahagan who designed the logo; Stephan Custer, Robert Breazeale, Laurence Lassen, Carter Gibbs, Robert Gibson, and Stewart Coleman who served as moderators; and a particular thanks to Kathy McDonald who processed all of the papers for this proceedings.

The world faces many environmental problems with acid rain, global warming, air pollution, and other factors affected by human activities. There are strong indications in the world literature that high-mountain ecosystems are particularly vulnerable to these disturbances and may indeed prove to be a sensitive monitor of subtle changes in the environment. The knowledge presented at this symposium should prove to be a springboard for accelerated research and intelligent management of these high-mountain ecosystems.

—WYMAN C. SCHMIDT
Project Leader and Research Silviculturist

CONTENTS

SESSION 1

High-Mountain Resources of the World

Wyman C. Schmidt
Session Coordinator

The papers in this section examine worldwide ecosystems that are similar to the high-mountain whitebark pine ecosystems of North America, providing an international perspective at a time of increasing concerns with changes in global environments. The primary purpose is to learn from the research and management of "Old World" ecosystems that have had many centuries of use and abuse, and attempt to capitalize on the knowledge gained there to better manage high-mountain ecosystems of the "New World" in North America. Papers in this session dealt with European and Asian findings and provided a glimpse into the future of high-mountain biological research in North America.

HIGH-MOUNTAIN FORESTS OF THE WORLD: ENVIRONMENTAL SIMILARITIES AND RESOURCE USE ISSUES

Jack D. Ives

ABSTRACT

The high-mountain forests of the world display remarkable similarities, at least from a physiognomic point of view (the inner tropics excepted). The lapse rate, in terms of its impact on the length and warmth of the growing season, is the most significant control on the upper limits of growth of these forests for any particular latitude. The principal environmental characteristics include: low temperature, high radiation receipts, azonal soils, high gradients, and potential slope instability, as well as relative inaccessibility.

Over much of the "Western" world inaccessibility and low growth rates of these forests have reduced their direct economic importance; dependency on fuelwood virtually ended some decades ago. This is not the case in Third World countries, where the manner of over-exploitation by subsistence peoples is closely following that which was typical of the Alps, for instance, throughout the Middle Ages and into the first decades of the present century. The most important resources of these forests relate to recreation and wildlife reserves, watershed management, and defense against mountain hazards. Efficient forest management is often hindered by the persistence of anachronistic forest laws that stand in urgent need of reappraisal and adjustment. Hand in hand with this, is the need for a much fuller understanding of two aspects of the dynamics of the mountain forest environment: (1) the history of deforestation (and natural reforestation); and (2) the actual physical impacts of deforestation, and especially the perceived distant downstream impacts.

ENVIRONMENTAL SIMILARITIES

The physical environment and associated resources of the world's high-mountain forests embrace an enormous topic of great complexity. In detail, upper montane forest belts and their forest-alpine tundra ecotones display considerable variation in terms of their floristics, topography, climate, soils, and in the histories of their resource use, as well as in their current status. Nevertheless, some useful generalizations can be made for the purpose of this conference on the whitebark pine ecosystems.

Temperature constraint is one common denominator of the world's upper montane forest belts. It is necessary to consider the progressive reduction in the length and warmth of the growing season with increasing altitude. On a global scale this "standard" lapse rate is the ultimate control on the altitude to which tree species can maintain themselves. It displays itself in simplified form by the regular reduction in the elevation of the highest surviving trees from the subtropics to polar latitudes (fig. 1). The 10 °C mean isotherm for the warmest month is frequently used as a surrogate for timberline but, as is generally understood, this isotherm conceals a great amount of complexity. And even this gross simplification breaks down between the tropics where, across the Equator in its extreme form, summer occurs every day and winter every night. In the inner continental interiors, such as the eastern Pamirs, and the Hoggar and Tibesti of the southern Sahara, extreme aridity prohibits establishment of any form of mountain forest belt. Nonetheless, on a world scale, the work of Arno and Habeck (1972), Hansen-Bristow and Ives (1985), Tranquillini (1979), Troll (1973), Wardle (1974), and others, can be combined by relating upper timberline in some very broad manner to temperature—in effect, the length and warmth of the growing season. This leads to a low latitude-high altitude to high latitude-low altitude energy continuum. A caution is needed even here, however, in that some tree species have the ability to live a very long time, especially those equipped to endure wind deformation and to reproduce assexually by layering. Thus it is necessary to be aware that the actual upper tree species limit, and the forest-alpine tundra ecotone as a whole, have the ability to withstand a degree of climatic vicissitude and may not necessarily be in synchroneity with the present climate, however that may be defined (Ives and Hansen-Bristow 1983). This has important implications for high-altitude forest management.

Any consideration of the functioning and manipulation (resource use) of high-mountain forests must relate to the temperature constraint on forest growth at altitude, which has several vital consequences. First, growth rates are progressively reduced with increasing altitude. In conjunction with steep slopes, however, this restraint is associated with azonal soils, frequently of low nutrient value. Thus, ecosystem manipulation based on short-term economic considerations can result in long-term environmental and economic losses. At issue here is the potentially very long recovery period, if recovery is at all possible, following disturbance. Witness the

Paper presented at the Symposium on Whitebark Pine Ecosystems: Ecology and Management of a High-Mountain Resource, Bozeman, MT, March 29-31, 1989.

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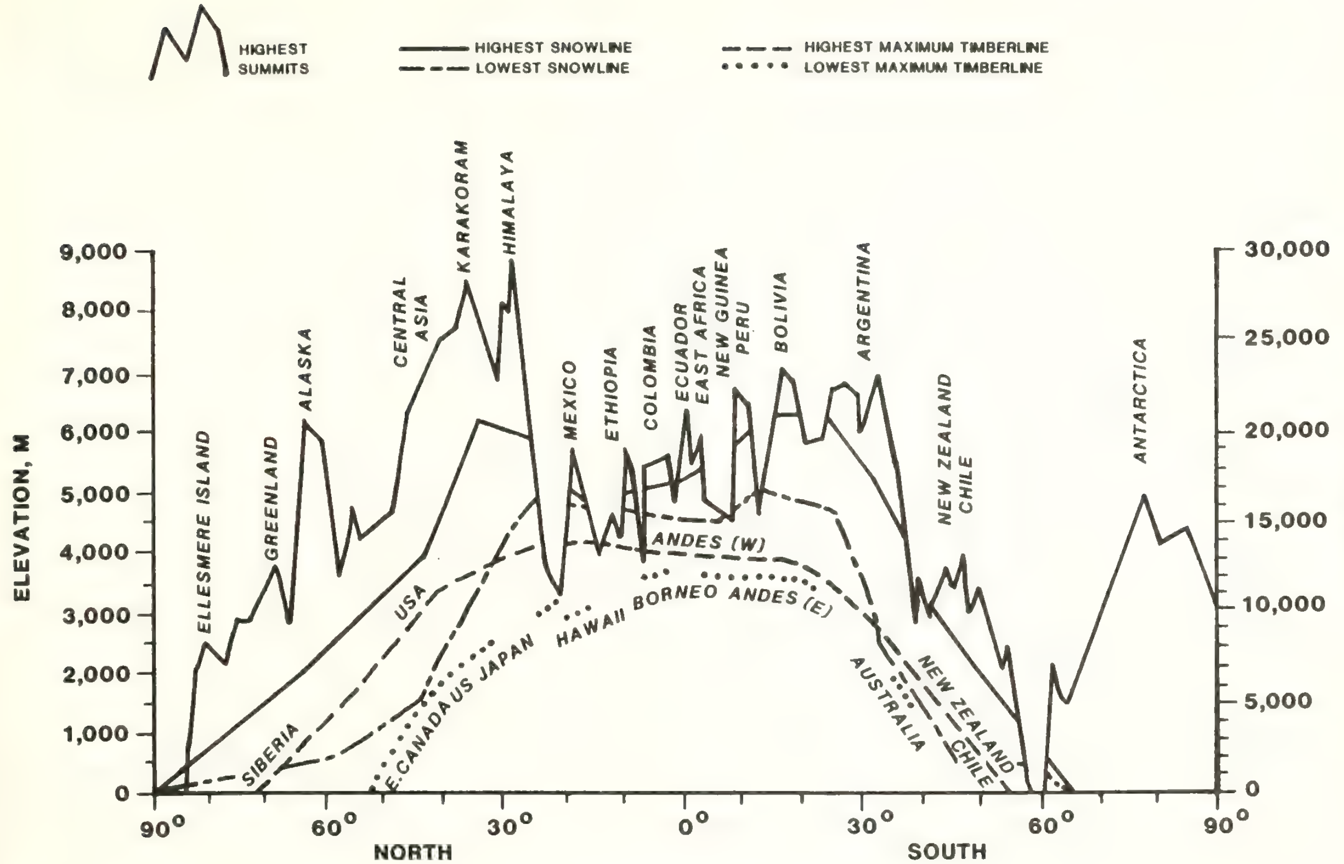

Figure 1—Global cross-section of the alpine regions, showing the highest summits, snowline, and timberline (Ives and Barry 1974; partly after Swan 1967).

lack of success in restoring timberlines in the Alps, despite much research and great expense in high-altitude planting.

These considerations are of particular value where climatic climax forests prevail—in other words, in the comparatively little disturbed high-mountain forest belts of North America. For much of the rest of the world upper timberlines have been extensively disturbed by human intervention, sometimes over thousands of years. This leads into the issue of the associated resources of the high-mountain forest belts: an issue beset with value judgments and resource-use conflicts.

RESOURCE USE ISSUES

Societies have undergone significant changes in the values placed on high-mountain forests. These changes have occurred over both long and short periods of time, and they also occur in space, in the sense that very different sets of values are placed on montane forest resources in different parts of the world today.

These changes in the value placed on high-mountain forest resources relate to the second common denominator—relative inaccessibility. In subsistence societies, such as the Alps of the Middle Ages, and the Himalaya and Andes of today, the forests both were, and are, closely integrated with subsistence living. Thus they provided multiple subsistence products, fuelwood not necessarily being the most important, together with a vital array of secondary products, such as wild game, berries, fruit, mushrooms, and open grazing for domestic animals. In many mountain areas it was the growing pressure on grazing land, to provide for increases in human populations, that led to extensive, even catastrophic, lowering of the upper timberlines. This is particularly well documented for the Alps.

From the perspective of present management of high-mountain resources in many developing mountain countries (the so-called Third World) a serious problem has arisen. This results from conflicts between aid agencies and governments, and mountain subsistence communities, in terms of how the forests are perceived. There is a "Western," or Eurocentric, view that regards the forests as a "sustainable resource," whereas many, although by no means all, mountain subsistence communities regard them as a "convertible resource." Thus, as long as mountain farmers view their forests as an opportunity for expansion of arable farming through forest clearance, it would appear that grandiose schemes for reforestation imposed from "outside" will have little chance of success.

The remainder of this paper will be devoted to a discussion of some of these issues. Brief case studies are presented to illustrate the complexity of high-mountain resource use issues on a global scale.

The Alps

As already mentioned, the Alps have experienced massive forest manipulation over many centuries. Deforestation of the upper montane forest belt, especially on *adret* (sunny) slopes, has resulted in progressive lowering of the timberline between 200 and 600 m (Tranquillini 1979). Periodic natural disasters, such as snow avalanches, mudflows, landslides, and floods, were recognized long ago to be related to unwise deforestation.

Several, if intermittent, attempts were made to control the loss of forest cover, but with limited success. Nevertheless, continued environmental deterioration resulted in the initiation of a series of forest laws in the closing decades of the last century that have been strengthened progressively up to the present (Price 1988). Switzerland, for instance, has a more extensive forest cover today than it had 90 years ago. However, during these last nine decades, the Swiss in particular, and residents of the entire Alpine region in general, have radically changed their perceived priorities of various upper montane forest uses. Subsistence use and export of commercial timber have virtually ceased. Esthetics, watershed management, and protection against natural hazards have come to dominate.

The irony is that current forest management is severely hindered by what were originally progressive forest laws and what are now anachronisms. The situation is made the more complex by the continued expansion of tourism, especially winter sports, and second home construction, and by the recent forest dieback, at least in part associated with atmospheric pollution. It is a remarkable fact that the cost of harvesting timber in the Alps is so high today that Finland has become a major source of lumber for Swiss mountain chalets.

The Rocky Mountains

Price's (1988) comparative study of the Swiss and Colorado forest laws and their impacts brings to light a number of fascinating points. The forest laws of the United States developed along lines very similar to those of Switzerland, both in terms of objectives and timing. More specifically in Colorado, pressure on the montane forests in the latter half of the last century derived predominantly from the mining boom and widespread firing, both natural and deliberate; this caused extensive official concern eventually resulting in enactment of a series of forest laws.

Once again, however, the majority of forest users today perceive the forests of the Rocky Mountains as valuable primarily for recreation, watershed management, wilderness, and wildlife preservation. There remain serious conflicts, nevertheless, in terms of ski resort and second home development and an economically marginal, but subsidized, timber industry. The controversy over fire suppression, at least in part, must be regarded as being exacerbated by now anachronistic forest laws.

The Nepal Himalaya

The World Bank (1979), many individuals (Eckholm 1976; Myers 1986), and many other agencies, have reiterated so often that Nepal will have no accessible forest cover by the year 2000 that this view of impending environmental disaster has had a momentous impact on foreign aid policy. The issue is a particularly fascinating one because a series of virtually "sacred" truisms has been used to convince governments, United Nations agencies, non-government organizations, and the conservationist public at large, that the "ignorant" and overly fecund mountain subsistence farmer, because of the supposed extensive deforestation, is responsible for massive damage to the life-support base of several hundred million people on the Ganges and Brahmaputra plains. This concern reached a crescendo in September 1988 when reportedly unprecedented flooding in Bangladesh, which put more than 60 percent of the entire country under water, was blamed in large part on the irresponsible mountain farmer. The Government of Japan is reportedly offering to collaborate with the United States and Bangladesh to reduce, or even prevent, future flooding through a series of massive infrastructural interventions, entailing the expenditure of billions of dollars. This would include extensive reforestation in the Himalaya, major headstream storage reservoirs, barrages, main channel canalization, and construction of artificial levees.

Unfortunately, the assumptions upon which such albeit preliminary policy formulation is based are at least largely unproven, or even totally false. This highly controversial statement is too complicated for adequate discussion here. It is the topic of a new book—"The Himalayan Dilemma: Reconciling Development and Conservation" (Ives and Messerli 1989). Yet some general statements are warranted.

Our claims concerning unproven, even false, assumptions are based upon an array of individual, small-scale studies that led to the serious questioning of the validity of many widely assumed cause-and-effect relationships that go to the heart of any attempt to evaluate the resource management approaches to high-mountain forests.

In many areas of the Himalaya, where reasonably reliable information is available, it appears that deforestation has not been a dramatic post-1950 phenomenon associated with the population explosion, as is so often stipulated (fig. 2). Deforestation in the Middle Mountains of Nepal (the region of major population concentration throughout history), and in many other parts of the Himalaya, was well advanced by the beginning of the 18th century and accelerated due to the imposition of government policy after the militant unification of Nepal under the House of Gorkha in 1769. Rapid conversion of mountain forest land to terraced agriculture was set in motion by the taxation structure, and continued throughout the last century. It appears, however, that by the 1930's most convertible forest land had been converted; the last 50 years have seen little change in forest area, although considerable depauperation of the remaining forest has occurred (Griffin 1988; Mahat and others 1986).

There is little reliable evidence to causally link deforestation, soil erosion, and landslide incidence (Ives and Messerli 1989, chapter 5), and there is even less support for the widely held assumption that land-use changes in the mountains have had serious impacts on the plains (Ives and Messerli 1989, chapter 6) (fig. 3). It has been claimed that Bangladesh is flooded because it periodically rains a lot (Hamilton 1987)! This seemingly outrageous statement demands the introduction of a number of others:

1. Deforestation on steep mountain slopes, particularly in tropical and subtropical regions, does not necessarily lead to increased soil erosion and slope instability—what rather is at issue is the manner of forest cutting and the alternative uses to which the cleared land may be put (fig. 4).

2. Despite widespread claims to the contrary, general Third World mountain deforestation is not a recent phenomenon.

3. Flooding and siltation on the flood plains of great mountain rivers, such as the Ganges, the Brahmaputra, and the Yangtze, are largely inevitable natural processes that have occurred throughout geological time. Recent deleterious impacts, if influenced to any extent by human activities, are more likely due to human intervention on the flood plains themselves, rather than to land-use changes in the upper catchments.

4. Deforestation is not necessarily "BAD."

5. Development of mountain resources requires sensitive understanding of the desires, objectives, and indigenous environmental knowledge of the local people.

Figure 2—Sindhu Palchok District, Nepal Middle Mountains, near Chautara. Is deforestation really bad? The densely wooded steep slopes in the distance give an indication of what the foreground would have looked like before human impacts initiated in the 18th century. Now these magnificently constructed and tended khet, or irrigated, terraces grow multiple crops of paddy rice and winter wheat. They also represent an excellent soil conservation approach to steep mountain slopes without outside aid or interference.

A

B

Figure 3—(A) Photograph from the Trisuli Road below Kakani, in the Nepal Middle Mountains. The landslide occurred during the preceding monsoon season, (1978) and was regarded as exceptionally unstable and likely to enlarge. (B) The same view as shown in (A), but taken in October 1987. It is now almost impossible to determine the location of the landslide and it is unlikely that, without access to photo (A), the visiting "expert" would ever understand the land-use history of this site. Several houses, visible in A, have been moved or pulled down and the forms of many of the undamaged terraces have changed markedly. This is a very dynamic landscape.

Figure 4—This hillside, Lalitpur outside the Kathmandu Valley, was previously photographed from the air in 1981 by Brian Carson. His picture showed more than a hundred landslides caused by torrential rain. Many of the landslide scars still can be seen but only very faintly. They are largely revegetated and careful inspection is needed. A casual visitor to the area would probably notice nothing unusual.

The Hengduan Mountains, Northwestern Yunnan

Many of the dire predictions for environmental collapse ascribed to the Himalaya have been used to categorize the high-mountain and plateau forest lands of southwest China. In 1985, 10 weeks were spent undertaking detailed biogeographic and geomorphic research in the Yulongxue Shan (Jade Dragon Snow Mountains) of northwestern Yunnan (Ives 1985; Ives and Messerli 1989). Somewhat similar conclusions were obtained to those outlined for the Nepal Himalaya. In this case it was concluded that much of the widespread deforestation of the Yunnan Plateau, attributed to Chairman Mao Tsedung, the Great Leap Forward, and the Cultural Revolution, actually represents centuries, if not more than a thousand years, of progressive conversion of forests to agriculture. In the higher mountains a very complex situation was at least partially unraveled. Replication of high-quality photographs, taken in the 1920's and 1930's by Dr. Joseph F. Rock and kindly made available by the National Geographic Society, facilitated direct comparisons of forest cover over a 50- to 60-year period (fig. 5). In some specific localities forest cover was more luxurious and forest canopy more complete in 1985 than in Rock's time; in other localities there was little discernable difference (fig. 6); and in yet others serious and recent deforestation had occurred (figs. 7 and 8). In part, this can be explained by differences in relative accessibility, but it is also related to management policies of local leaders (fig. 9).

These general remarks are in no way intended to indicate that China does not face serious land-use problems in the important forest region of the southwest. Rather they support the claim that there is a need for development of a much longer historical perspective. The lesson to be learned, once again, is that mountains, and mountain peoples, are extremely diverse from region to region and that generalization and simplification are fraught with the risk of producing inaccurate conclusions. In addition it raises a challenge to the tendency for overdramatizing environmental catastrophe without first obtaining reliable data.

CONCLUSIONS

What can be learned from the foregoing, admittedly all too brief, commentaries on widely scattered areas of the high-mountain forests of the world? How is this relevant to concerns about the ecology and management of the whitebark pine ecosystems?

It would seem evident that we are still lacking high-quality, replicable information about high-mountain forest ecosystems, and this is likely as true for Montana as it is for the Alps and the Himalaya. It follows that, in view of the limited available resources for effective research, a rigorous intellectual approach is needed for the identification of vital gaps in knowledge so that the research resources that are available can be used most effectively. A corollary is that a much more efficient system for sharing information and experience is required. A succession of conferences to follow this one should be seriously considered.

A

B

Figure 5—(A) Photograph taken in 1928 by Dr. Joseph F. Rock, Lijiang autonomous county, northwestern Yunnan. The time is postmonsoon and the doline is partly filled with water forming a shallow lake; it is usually dry by the following spring. Note the rather poor condition of the forests, both in the foreground, and especially on the steep slope on the right, and on the opposite side of the lake. (Courtesy, Dr. Barry C. Bishop, National Geographic Society). (B) Replicate of photograph shown as (A) taken in April 1985 by the author. The lake is now dry because of the season. Note the closed crown cover on the steep hillslope to the right. Also, despite the considerable distance, it is clear that the forests on the far side of the lake are more extensive and more luxuriant than they were in 1928.


A


B

Figure 6—(A) The east face of the Yulongxue Shan, northwestern Yunnan, as seen by Dr. Joseph F. Rock in 1928. Rock's camp is situated on the far side of the karst lake. The forest cover in the middle ground is somewhat open and immature, being cut over and fired from time to time. (Courtesy Dr. Barry C. Bishop, National Geographic Society). (B) The same scene as that shown in (A), but taken in April 1985 by the author. The lake is now dry. The conspicuous rock in the foreground greatly aided the location of Rock's camera position. The forest in the middle ground is in approximately the same condition although most of the trees are only 25 to 40 years old (based on tree ring count); the area is being actively harvested today. Most of the trees of Rock's time were subsequently felled.

Figure 7—Hengduan Mountains, northwestern Yunnan, People's Republic of China. With the recent (post-1979) improvement in housing, additional pressures have been put on the forests nearest the villages. This view in Lijiang autonomous county looks across the Jinsha Jiang (Yellow River) onto heavily impacted mountain slopes. Note the numerous skid trails, some converting into gullies, with the more inaccessible slopes retaining a much fuller forest cover.

Figure 8—Large sections of the Yunnan Plateau have been totally deforested and soil erosion has proceeded to such an extent that the C-horizon has disappeared exposing the bedrock. This scene is traversed by the main road between Kunming and Dali, which is lined with eucalypts. Only on sheltered valley floors has enough soil been preserved to permit agriculture. Natural climax vegetation would be closed-crown monsoon rain forest. This deforestation, however, occurred hundreds of years ago, if not more than a thousand.

Figure 9—A once densely forested section of the high Yunnan Plateau between the Jinsha Jiang and the Mekong trench. Lack of coordination between loggers and transport authorities resulted in many square kilometers of logs being left on the ground to rot. In contrast to figure 8, this is modern, and very destructive, deforestation.

It also seems arguable that much that pervades the popular press, as well as some of the scientific literature, may be based upon misconceptions, false assumptions, even manufactured data. There is the need to challenge unproven assumptions in the context of good research that should lead to better management of high-mountain ecosystems. Mountains, even those without indigenous cultures of many centuries standing, are some of the world's most complex biophysical systems. Therefore, superficial generalization can lead to ill-founded conclusions, and in turn, misconceived management policies. It follows that the mountain researcher has a responsibility to enter the political arena and help correct false impressions that are being generated among the public at large.

The earlier remarks, suggesting a lack of relationship between deforestation and soil erosion, implying that deforestation is not necessarily "BAD," therefore, it might be "GOOD," are not intended as relevant to the whitebark pine ecosystems. What I would urge, however, is that, in our evaluation of high-mountain resource management issues, we must avoid mixing value judgments, old wives' tales—or "sacred cows," if you will—and scientifically based conclusions. But we must also recognize that society's values change with time and vary widely from one part to another of our present-day world. There is a need to demonstrate, unemotionally, that forest laws, or land management regulations in general, frequently do not keep pace with the changing values; this in turn has important implications for effective management. Additionally, the prospects for long-term environmental and economic losses that can ensue from unsound manipulation of these cold-stressed mountain forest ecosystems must be presented forcefully to the decision makers concerned.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from Lawrence McHargue)—In view of some similarities in both terrain and climate, are any of the pines of the Central Asian mountains as long-lived as *Pinus* spp. around the Great Basin?

A.—I have no direct information with which to answer this question, nor have I been able to find anything in the literature. But now that the Central Asian mountains are becoming much more accessible, it would be most interesting to find out.

Q. (from Ray Brown)—You mentioned that one of the best things we in western countries could do for people in high-mountain regions of the Third World would be to leave them alone. However, we have learned a great deal about such things as revegetation techniques for alpine-subalpine disturbances, natural successional processes in these life-zones, and methods of selecting adaptive native

plant species for revegetation practices. Don't you think we could initiate a program wherein we, on both sides, could demonstrate and teach what we have learned, and also learn from them new approaches and techniques? If not, why not?

A.—I have to agree that such a course ought to be very worthwhile. I am not so much dedicated to the isolation of mountain minority groups in the Third World, as to the need to treat them, both collectively and individually, as equals. In such circumstances the learning process would be two-way. Foreign aid would then progress from being a charity (a humiliating experience) to gift-exchange (an elevating experience). As "mountaineers" we should be enthusiastic about the latter! My remarks that provoked this eminently reasonable question were essentially a reaction to the nearly pervasive imposition of "outside" and "appropriate" (so often inappropriate) technologies that have frequently caused more harm than good, despite the sincerity and goodwill associated with them.

Q. (from Harry Hutchins)—How can we work with local cultures to improve subalpine forests in areas such as Tibet and Yunnan, China?

A.—I think that there is a good chance to work with local cultures in Tibet and Yunnan, despite the current political difficulties. It first would be necessary to achieve a sensitive collaboration on two fronts, both with the Chinese authorities and the local people. I think that the former would be relatively easy in many situations; the latter more difficult. However, the recent work of Drs. M. Goldstein and C. Beall, as anthropologists working with the nomads on the Tibetan Plateau (see National Geographic Magazine, June, 1989) is cause for considerable optimism. I am implying here that much of the "environmental" problem is political at several levels; it is necessary to break through the communication difficulties and to find a truly appropriate approach.

Q. (from Tad Weaver)—Why have agricultural terraces been deserted in the Soviet Pamirs? Is there similar desertion elsewhere?

A.—The abandonment of agricultural terraces in the Soviet Pamirs was primarily a 1930's to 1960's phenomenon. During this period marginal mountain peoples were attracted to the commune and state farms of the lowlands in response to the labor shortage with the development of irrigated agriculture (cotton and fruit). Widespread mountain depopulation occurred. Since 1986 a reverse flow has developed, the impacts of which will be extremely interesting to follow.

BIOLOGY, TAXONOMY, EVOLUTION, AND GEOGRAPHY OF STONE PINES OF THE WORLD

Ronald M. Lanner

ABSTRACT

*Stone pines (*Pinus *subsection* Cembrae*) are morphologically defined by wingless seeds and cones that remain closed at maturity, retaining their seeds within. These characteristics have been attributed to selection by the nutcracker (*Nucifraga *spp.), which caches seeds of these pines, causing them to regenerate from subsoil caches. Arguments are presented in support of retaining* Pinus pumila *Regel and* P. albicaulis *Engelm. in* Cembrae. *New data are presented on seed retention in* P. koraiensis *cones. Stone pines are shown to have similar environmental tolerances and successional roles.*

INTRODUCTION

The Stone pines are those species of section *Strobus* that have five-needled fascicles, wingless seeds, and cones that remain closed at maturity (subsection *Cembrae* Loud.) (Little and Critchfield 1969). They are whitebark pine (*Pinus albicaulis* Engelm.), Swiss stone pine (*P. cembra* L.), Korean stone pine (*P. koraiensis* Sieb. and Zucc.), Japanese stone pine (*P. pumila* Regel), and Siberian stone pine (*P. sibirica* Du Tour). The uniting of these species into a group or subsection has been common practice since Shaw did so in "The Genus Pinus" (1914). It is not without controversy, as we shall later see.

Winglessness is a common trait in the subgenus *Strobus* (fig. 1), though it is rare among the hard or yellow pines of subgenus *Pinus*.

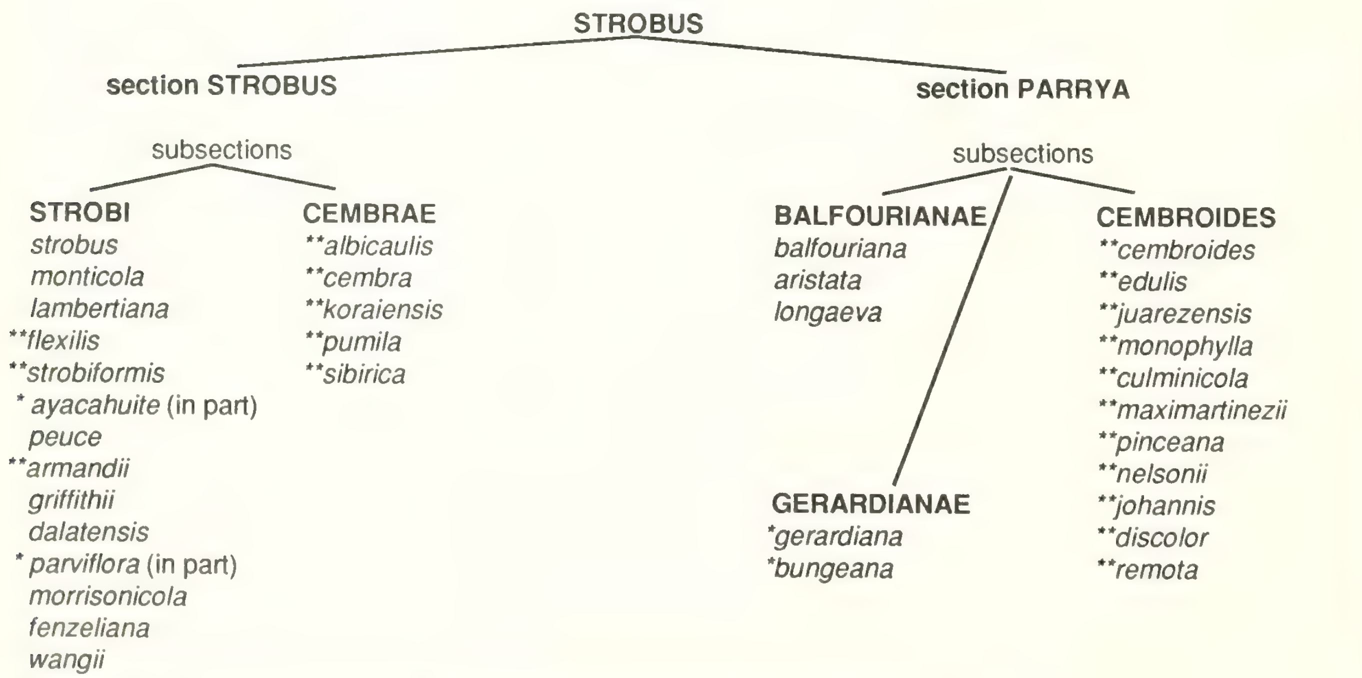

Figure 1—Distribution of wingless-seeded (**) and nearly wingless-seeded (*) pines within subgenus *Strobus*.

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The "indehiscence" of cones (Little and Critchfield 1969; Shaw 1914) is, in contrast, absent from all other pine subsections, and it is this characteristic that really sets the stone pines apart.

It sets them apart not only in the taxonomic sense, as a diagnostic morphological feature, but in a more profound sense as well. This strange cone, and the wingless seeds within, provide an essential link to those corvids of the genus *Nucifraga*—the nutcrackers—that have played a central role in the biology, taxonomy, evolution, and geography of these fascinating pines. That is a very long story, and one that cannot be comprehensively covered in this paper. Instead, I will discuss just a few of the issues regarding the *Cembrae* that have received relatively little attention, with the objective of showing the essential coherence of this group of species.

BIOLOGY

In the only detailed report on the behavior of stone pine cones, Lanner (1982) showed that many undisturbed *albicaulis* cones remain on the tree and retain their seeds at least until the following July, long enough for the seeds to become inviable. The cone scales become loose in the fall, but do not part enough to allow seeds to fall out. Failure of the scales to reflex is apparently due to the absence of a layer of coarse tracheid strands beneath the adaxial surface—as first pointed out by Shaw (1914)—which, in other pines' cones, shrinks longitudinally, pulling the scale open (Harlow and others 1964). The absence of that tissue also makes the cone scales brittle and easy to break off, despite the formidable appearance lent by their massive apophyses. When they are broken off, the fracture zone is usually just distal to the midpoint of the subtended seeds, so most of the seeds remain in place, held in the "core" of the cone. Thus scale removal displays their seeds to the animal that removes the scales (Lanner 1982). These morphological and anatomical traits (fig. 2) facilitate the harvest and dispersal of *albicaulis* seeds by Clark's nutcracker (*Nucifraga columbiana* Wilson), as described in detail by Tomback (1978). Prior to ripening, the cones are pulpy, and can be pecked apart by nutcrackers feeding on the immature seeds.

The visibility of exposed stone pine seeds may be enhanced by conspicuous dark-brown to black markings (about 3 by 4 mm) on the hilum. These prominent "eyes" are not found in *albicaulis*, but occur on seeds of *koraiensis* from Japan (fig. 3), *sibirica* from Symansky Pass, Siberia, and *cembra* from the Austrian Alps. Sketches by Saito (1983a; 1985) show them in Japanese *pumila* as well.

Following harvest, nutcrackers cache many whitebark pine seeds in the soil, allowing those not later recovered or destroyed by predators to germinate. Thus the cone characteristics of *albicaulis* help ensure its regeneration. In a comparative study that assessed the role of nutcrackers and other animals in *albicaulis* regeneration, resident mammals and birds other than nutcrackers "did not have the requisite behaviors to systematically disperse or establish whitebark pine, and the pine was therefore dependent on the nutcracker for its regeneration" (Hutchins and Lanner 1982).

Figure 2—Mature *Pinus albicaulis* cones that are intact (left), partially divested of scales so as to expose the seeds within (upper right), and completely divested of scales and seeds, showing fragility of fracture zones (lower right). (From Lanner 1982.)

The situation appears similar among the other stone pines. *Pinus cembra* has been studied in detail by a number of investigators (Crocq 1978; Holtmeier 1966; Mattes 1982; Oswald 1956) in the Alps of Austria, Switzerland, and France. Its relationship there with the European nutcracker (Common names of subspecies of *N. caryocatactes* follow Dement'ev and others [1954]). *N. caryocatactes* ssp. *caryocatactes* is strikingly similar to the *albicaulis*-Clark's nutcracker mutualism. According to Oswald (1956) natural reproduction of *cembra* without the nutcracker is "scarcely conceivable." Mattes (1982) referred to the nutcracker as "an essential help in reforestation." In Poland, where specific studies of nutcrackers appear not to have been made, the nutcracker's role as a "sower" of *cembra* has been recognized (Myczkowski and others 1975). A difference between *cembra* and *albicaulis* is that seeds of the former are cached on stumps and in trees as well as in the soil (Holtmeier 1966; Mattes 1982). Seeds of *sibirica* are cached beneath moss polsters (Konev 1952).

Studies in the Soviet Union have shown an almost identical situation in the Urals and across much of Siberia, where the Siberian nutcracker (ssp. *macrorhyncos*) harvests and stores the seeds of *P. sibirica*, a

Figure 3—"Eyes" formed by the dark hilum of *Pinus koraiensis* seeds exposed by removal of cone scales.

species of economic value for its edible nut crops as well as its timber. Turcek and Kelso (1968) documented the extensive Russian literature on this subject.

In the Far East research has been less active. Little information is available, for example, on the harvest and storage of *P. koraiensis* seeds by the Siberian nutcracker, which is found throughout the range. This was true of *pumila* until the recent studies of Saito (1983a; 1983b; 1985), performed in a mountainous area of northern Hokkaido. Not surprisingly, Saito reported Japanese nutcracker (ssp. *japonicus*) behavior and *pumila* ecology almost exactly like that reported in Europe and North America, with allowances for such differences as the often-prostrate habit of the local stone pine species. According to Saito, the Japanese nutcracker is "the most effective disseminator of seeds of the (Japanese stone) pine" (Saito 1983a).

The strength of the stone pine-nutcracker interaction is dramatically illustrated by events—published here for the first time—in the lake district of southern Finland during the past two decades. Finland has numerous plantations of *sibirica* that were established as a hedge against crop failures when that country was under the Russian czars, apparently a common practice in Scandinavia and Russia (Holzer 1972). In 1968 Siberian nutcrackers invaded from the east, and a population of 10 to 15 pairs subsequently settled in Punkaharju. Ornithologists from nearby Savonlinna have observed these birds breeding in the vicinity, and congregating among the stone pines each fall, where they harvest pine nuts. Regeneration of *sibirica* has been observed some distance from the seed stands, presumably due to nutcrackers transporting and caching the seeds (Koski 1987; Vaisanen 1987).

The interaction of stone pines with nutcrackers has important biological consequences for the trees. To the degree that regeneration depends on seed caching by nutcrackers, site is determined by the bird's caching preference. Thus the tree will seldom have the opportunity to establish on a site not used for caching; but it will frequently have that opportunity on sites where nutcrackers do make seed caches. Caching does not automatically lead to seedling establishment, but merely creates the potential. Sites on which stone pines become established should be regarded as a sub-set of sites on which nutcrackers cache seeds. When sites within the range of both organisms lack stone pines it may be due to a lack of caches, or failure of cached seeds to become established.

Regeneration of stone pines from seed caches results, characteristically, in multiple germinations that lead to a high frequency of clumped stems (table 1). Clumping data have been reported for all the stone pines except *P. koraiensis*. The occurrence of many of a stone pine's stems in clumps has genetic implications. Furnier and others (1987) found that *albicaulis* trees within a clump were far more closely related to each other than to trees of other clumps, probably because they originated from seeds of the same cone; they were sibs or half-sibs. Such a genetic structure can potentially lead to heavy inbreeding, but this has not yet been examined.

Because nutcrackers cache seeds in an array of sites exhibiting a variety of physical and vegetational conditions, they become a factor in successional development. For example, *albicaulis* colonizes burned-over areas and rocky outcrops; or it may grow up through the gaps of an older canopy consisting of *albicaulis* and Engelmann spruce (*Picea engelmannii*), thereby acting as both a pioneer and a climax species (Lanner 1980). In a study of *albicaulis* establishment on the meadows of Squaw Basin in Togwotee Pass, WY, Snethen (1980) showed that this species was a pioneer on rocky outcroppings and moraines, and that only after pine groves had become established did Engelmann spruce grow up in their shade. Eventually the shade-tolerant spruce dominated the canopy, but nutcrackers continued to cache *albicaulis* seeds in the forest, maintaining large seedling and sapling populations of that species. The net effect of nutcracker activity in Snethen's study area was to accelerate secondary succession from a sagebrush (*Artemisia*)-grass mixture to a spruce-pine forest. As individual tree groves expanded, they formed a near-continuous cover, the shade of which supported numerous plants and animals not present in the sagebrush-grass vegetation type. In this

Table 1—Frequencies of multistem clumps among stone pines (*Pinus*, subsection *Cembrae*)

Tree species	Place and reference	Number of trees in sample	Trees in multistem clumps	Stems per clump
		n	*Percent*	*Range*
P. albicaulis	Wyoming, USA			
	(Lanner 1980)	1,270	47	2-8
P. cembra	Alps, France			
	(Crocq 1978)	167	89	2-11
		156	70	2-6
	(Lanner 1988)	154	66	2-6
	Alps, Switzerland			
	(Mattes 1982)	345	31	2->7
		214	39	2->7
P. pumila	Hokkaido, Japan			
	(Saito 1983a)[1]	69	94	2-19
P. sibirica	Sayan Mts., Siberia, USSR			
	(Konev 1952)[2]	ca. 3,600	—	2-23

[1]Saito's (1983a) data are based on seedlings, therefore avoiding errors that could be incurred due to layering of branches in this species.
[2]Percent of trees in multistem clumps cannot be calculated from Konev's (1952) data.

sense the nutcracker was a builder, or "edificator" of ecosystems in the sense of Reimers (Turcek and Kelso 1968). Reimers (1953) reported on the reforestation of *sibirica* by nutcrackers following fire and large-scale defoliation. Zykov (1953) pointed out the establishment of this species on the tundra margin.

Several authors have reported *P. cembra* in European larch (*Larix decidua*) stands, forming an understory. In Wyoming, whitebark pine sometimes becomes an understory in lodgepole pine (*Pinus contorta*) stands or in groves of quaking aspen (*Populus tremuloides*).

The environments in which the various stone pine species grow bear a striking resemblance. *Albicaulis* is found "in the highest elevation forest and at timberline" in a climatic zone that is "cold, windy, snowy, and generally moist" (Arno 1989). It is commonly associated with Engelmann spruce.

Pinus cembra was described by Plaisance (1977) as "an Alpinist . . . on bare rock to 2,400 m (7,900 ft), braving storms, snow, ice, wind." It too has a spruce associate, *Picea abies*.

Mirov (1967) stated that *sibirica*, which grows "in plains, in river valleys, and in the mountains of northern European Russia and Siberia" also occurs up to timberline in the Altai Mountains. According to Malyshev (1960) it reaches 1,950 m (6,400 ft) in the rugged Eastern Sayans, where its creeping, flat-topped growth resembles that of *pumila* growing in the alpine zone. Its common spruce associate is *Picea obovata* (Haddock 1977).

Pinus pumila "grows on very cold sites . . . in exposed and windy places" and cannot survive climates with hot summers (Saho 1972). Again, there is a spruce—*Picea glehnii*—associated with it in Hokkaido (Saito1985), and probably *Picea obovata* in Kamchatka.

Pinus koraiensis is found on a wide range of sites, from the relatively mild summer-rain region of Korea to the subarctic forest zone where it experiences temperatures as low as –35 °C (Hyun 1972). In Japan it is associated with *Picea jezoensis*.

It is beyond the scope of this paper to catalog the birds and mammals common to stone pine forests, but in addition to nutcrackers, chipmunks, squirrels, jays, and other animals typical of northern coniferous forests worldwide are common inhabitants of stone pine forests.

TAXONOMY AND EVOLUTION

Critchfield (1986) recently summarized the most commonly cited classifications of the white pines, including the stone pines, so there is no need to do so here. Instead, I will review and rebut Critchfield's reasons for rejecting the stone pines as a cohesive group of species sharing a common ancestor; and for suggesting that *pumila* and *albicaulis* do not belong with the "core species" of the *Cembrae*.

Critchfield (1986) expressed skepticism that the *Cembrae* really share "indehiscent" cones. He wrote:

"The indehiscent cone does not necessarily remain tightly closed at maturity" and detailed information on this point is "sparse and contradictory." He pointed out that in *albicaulis*, cone scale separation occurs "sometimes;" and that it is "usual" in *koraiensis* and *pumila*. This is misleading. I reported (Lanner 1982) that *albicaulis* cone scales become "loose enough to be displaced about 1-2 mm with slight pressure on the apophyses . . . upper scales frequently part as much as 8 mm, allowing seeds inside to be seen, *but not enough to let seeds fall out when the cone is turned or shaken*" (emphasis added). This is the important point, because the retention of seeds in the cone has been suggested as a nutcracker-selected characteristic that facilitates harvest of the seeds (Lanner 1982).

With regard to *koraiensis*, of which little has been written, I report here unpublished data of which Critchfield was unaware:

In December 1981 I experimented with mature 1981 *koraiensis* cones provided by the Kanto Forest Tree Breeding Institute at Mito, Japan. On many cones, several seeds were visible between slightly parted scales, especially in the distal area.

Experiment 1. Twenty-five cones each from lots Ohtaki-101, -104, -116, and -123 were rotated while being shaken. From these 100 cones only 11 of an estimated 8,140 seeds shook loose (0.14 percent).

Experiment 2. On 10 cones each from lots Ohtaki-101 and -123, 10 scales from mid-cone were broken off by finger pressure. The number of exposed seeds held in the cone core was counted. Cones were shaken and rotated, and the fallen seeds counted.

In lot 101, 160 seeds were exposed by removing scales; 41 of these (26 percent) were shaken loose. In lot 123, 131 seeds were exposed, of which 50 (38 percent) were shaken loose.

I conclude that *koraiensis* cones remain closed tightly enough to retain all but a minor portion of their seeds. (In February 1989, more than 7 years after being picked, they had opened no further). The majority of seeds are retained in the cone even after scale removal and vigorous shaking.

With regard to *pumila*, Saito (1983b) stated unequivocally: "The mature cones remain closed and do not release their seeds." Critchfield (1986) did not question the seed-retention abilities of *cembra* or *sibirica* cones, but should such questions arise in the future, the following should be noted: Crocq (1978) described how nutcrackers break off *cembra* cone scales one by one and added: "a dozen seeds or more are thus exposed." As for *sibirica*, I have found, in a cone from Symansky Pass, that seeds do not fall out when the cone is turned even after the scales are removed. It should be pointed out that these observations merely confirm Shaw's (1914) unequivocal characterization of all the *Cembrae* as having "indehiscent" cones that are "inert under hygrometric changes and may always be recognized in herbaria by their persistent occlusion . . .". Critchfield's (1986) skepticism of the effectiveness of these cones in retaining their seeds has, therefore, little basis.

Critchfield (1986) relied on de Ferré (1966) for findings that suggest *pumila* has closer affinities to *parviflora* than to the *Cembrae*. But de Ferré's conclusions are hardly definitive. For example, she wrongly stated that *parviflora*, like *pumila*, is wingless. This is not so (see below). De Ferré (1966) pointed out that *pumila* and *parviflora*, unlike *cembra* and *sibirica*, have folds in the walls of their mesophyll parenchyma cells, as do all other pines (Critchfield 1986). A later study of mesophyll cells showed that of three subtypes of cells with folds among *Cembrae* and *Strobi* species, *pumila* and *albicaulis* were of subtype 1, *koraiensis* and *armandii* of subtype 2, and *strobus* and *flexilis* of subtype 3 (Litvintseva 1974). And in a study of pollen morphology, Kuprianova and Litvintseva (1974) placed *pumila* with *cembra* and *sibirica*. De Ferré (1966) also found that both *pumila* and *parviflora* have warty epidermal cells and thick-walled subepidermal cells; but they differed in needle resin duct diameter and presence of sclerified fibers in the central cylinder. When cone-scale umbos and mucros are the criteria, *pumila* is again placed with *cembra* and *sibirica*, with *parviflora* ancestral to many of the *Strobi* (Klaus 1980).

There is similar interspecific variation among the *Cembrae* species in oleoresin composition and in heartwood phenolics. Using the latter characteristic as a common denominator, Critchfield combined *koraiensis*, *cembra*, and *albicaulis* with *ayacahuite* and *flexilis*. He suggested this group has phylogenetic significance but admitted "it is not readily compatible with any other proposed scheme of white pine relationships." In fact, it appears that "affinities" are in the eye of the beholder, and are determined by the characteristics chosen for study.

It seems risky to connect *pumila* closely to *parviflora* because of the unsettled nature of *parviflora*, which is regarded by many Japanese specialists as consisting of two species, *P. pentaphylla* Mayr in the north and *P. himekomatsu* Miyabe and Kudo in the south (Saho 1972). Numata (1974) referred to *P. parviflora* var. *pentaphylla*, *P. pentaphylla*, and *P. pentaphylla* var. *himekomatsu* within the covers of the same book! The southerly taxon, *himekomatsu*, has large seeds with reduced wings. The northern, *pentaphylla*, has large seeds with longer wings that are, however, stubbier than wings typical of wind-dispersed *Strobus* pines. According to Saito (1986), Japanese nutcrackers disseminate the seeds of *pentaphylla*. I predict that further study will show *himekomatsu* to be a nutcracker-dispersed species; and that its relationship to *pentaphylla* will be analogous to that of *flexilis* to *strobiformis* (Lanner 1980).

Let us now examine Critchfield's reasons for linking *albicaulis* to the *flexilis* complex. He stated that except for its cones, *albicaulis* "closely resembles" *flexilis*, but this overlooks clear differences in bark characteristics and pollen cone color. In addition to similarity in the number and placement of their accessory needle resin canals, *albicaulis* and *flexilis* share three other characteristics (Critchfield 1986):

1. Their needles have few or no marginal teeth.
2. Their needles have many stomata on abaxial surfaces.
3. The transition of vascular tissue arrangement occurs in the base of the hypocotyl rather than in the vicinity of the cotyledons, according to de Ferré (1965).

But as Critchfield pointed out, none of these traits is unequivocal. Marginal teeth, for example, are "sometimes sparse or obscure" in *pumila* and in three other white pines. Abaxial stomates also are found in *strobiformis* and *monticola*. In addition, the pinyons provide an example of an unquestioned subsection (*Cembroides*) in which some species lack abaxial stomates (*P. juarezensis, P. discolor)* while others have them (*P. edulis, P. cembroides)*. The vascular organization that characterizes *albicaulis* and *flexilis*, which occurs only in "a minority of their seedlings," occurs also in *monticola, ayacahuite*, and *aristata*. On the other hand, *albicaulis* and *flexilis* have the same pollen type (Kuprianova and Litvintseva 1974), and they share umbo and mucro characters (Klaus 1980).

Crossing results are equally inconclusive. Although *albicaulis* and *flexilis* commonly occur together at intermediate elevations (for example at 2,400-2,600 m [7,900-8,540 ft] in Togwotee Pass, WY), no suspected hybrids have been reported. Bingham and others (1972) reported 20-50 attempted crosses of *albicaulis* x *flexilis* resulted in less than one filled seed per cone. The hybridity of these seeds was not authenticated. Critchfield (1986) added that in seven of 14 other crosses, seven mature cones were produced. Four of these yielded sound seeds that were intermediate to the parents in germination characteristics. But the putative hybrids resembled *albicaulis* in their slow growth rate at the Institute of Forest Genetics, Placerville, CA. They subsequently languished and died, their hybridity never having been established (Critchfield 1989).

Critchfield (1986) therefore concluded that the proposed monophyletic origin of the *Cembrae*-type cone is undermined; that *P. pumila* is most closely allied to the *P. parviflora* group; and that *P. albicaulis* stems from the *P. strobiformis-P. flexilis* line. This required him to postulate that the indehiscent cone "has evolved independently at least twice in Eurasia . . . and once in North America . . . ." In other words, the *Cembrae* pines are end-products of convergent evolution in independent lineages.

Despite Critchfield's formidable argument, I think there is still a strong case that the *Cembrae* cone evolved once, under the selective pressure of an early nutcracker progenitor, and that speciation following that event has resulted in *albicaulis, cembra, koraiensis, pumila*, and *sibirica* (Lanner 1980; 1982). I base this argument on two grounds:

First, the cones of the *Cembrae* pines, whose unusual features have been interpreted as adaptations to nutcracker seed harvest (Lanner 1982), are similar in such detail that postulated origins in three gene pools on two continents grossly violate the concept of parsimony usually striven for in science. Second, in other cases where seed-retaining cones have evolved, convergence has not occurred.

For example, within the subsection *Cembroides*, the pinyon pines, every species has cones that hold their seeds in the seed cavities with flange-like fragments of spermoderm (fig. 4). This characteristic is unknown in other pines, and is perhaps the defining morphological characteristic of this ecologically and geographically coherent group.

Figure 4—*Pinus monophylla* cone showing the flange-like extensions of cone-scale tissue preventing seeds from falling.

The two nearly-wingless-seed species of subsection *Gerardianae* have evolved different seed-wing adaptations to retain seeds in the cone. *Pinus gerardiana* has reduced wings that adhere to the lower surface of the scale above. This was first noted by Shaw (1914), and I have confirmed it in a large number of cones from the Himalaya. In *P. bungeana*, the tip of the greatly reduced wing adheres to the upper surface of *its own scale* (fig. 5). This wing-tip is membraneous, but wing tissue forms a thick wreath around the seed.

Only one other white pine has seeds that are retained in the cone—*P. parviflora* (fig. 6). It has "seeds with a large nut and a short broad wing, often temporarily adherent to the cone-scale and breaking apart at the fall of the nut . . . . The frequent but not invariable retention of the seed-wing in the cone is due to adhesion. Many seeds fall with their wings intact, others break away from the wing which, after awhile, loosens and also falls" (Shaw 1914). This appears to be the least effective of the seed-retention mechanisms. Yet, that of *pumila*, which Critchfield views as an offshoot of *parviflora*, is an example of the most effective. *Pinus pumila* has completely wingless seeds, and an indehiscent cone; *parviflora* has winged seeds and cones that open normally. I think it is reasonable to regard the various seed-retention mechanisms—those of the *Cembrae* pines, the pinyons, *gerardiana, bungeana*, and *parviflora*—as having evolved independently. All the *Cembrae* are known to be "Bird Pines," as are several of the pinyons (Vander Wall; Vander Wall and Balda 1977, 1988) and *parviflora* var. *pentaphylla* (Saito 1986). The nutcracker subspecies *N. macella* occurs with *bungeana* (Dement'ev and others 1954). *Pinus gerardiana* has not yet been found subject

Figure 5—Cone of *Pinus bungeana* showing adherence of the narrow seed-wings to the cone scale. The seed-wing at right center has become separated from its seed during handling, but still adheres to the cone scale.

Figure 6—Cone of *Pinus parviflora* showing adherence of the tip of the seed-wing to the cone scale surface. These seed-wings have become separated from their seeds, perhaps due to handling.

to avian seed dispersal, but a nutcracker subspecies (*multipunctata*) is endemic to this pine's distribution area (fig. 7).

After considering the evidence summarized above, Critchfield (1986) commented that "the contradictions between reproductive characters, vegetative morphology, crossing data, and biochemical variations appear to be irreconcilable, and to undermine most classifications of the species within section *Strobus*." His solution is to seek common characteristics unrelated to coevolved cone and seed adaptations. This, of course, can only fragment the *Cembrae*. I would prefer to regard those cone and seed characteristics, consistent within the *Cembrae*, as evidence of speciation from a common ancestor. In other words, I see the nutcracker progenitor as the ultimate architect of these pines. The numerous solutions to the problem of the seed-retaining cone suggest that they vary with the gene pool that is challenged, and it seems unlikely that *Cembrae*-type cones, having evolved once, would do so again.

A final comment on the origin of *albicaulis*: elsewhere I (Lanner 1980) have argued that the patterns of variation in nutcrackers and stone pines are similar. Dement'ev and others (1954) recognized 10 subspecies of the Eurasian nutcracker, while Clark's nutcracker has no recognized subspecies. Eurasia holds four stone pines of which all but little-known *koraiensis* have several named botanical forms, varieties, or subspecies. In contrast, *albicaulis*, the only North American stone pine, has none. These patterns are consistent with a long occupation of Eurasia by both bird and pine, and a recent arrival of both across the Bering land bridge. Amadon (1944) offered other reasons for regarding *Nucifraga* as being of Old-World origin. My conclusion may be arguable, but the important point is that the evolution of stone pines cannot be profitably discussed without also considering the nutcracker.

GEOGRAPHY

Pinus albicaulis is North American; the other stone pines are Eurasian. The eastern range of *albicaulis* is mainly in the Northern Rocky Mountains of western Wyoming, western Montana, central and northern Idaho, western Alberta, and British Columbia. Outliers to these populations occur in northern Nevada and northeastern Oregon. A second series of populations extends southwards down the Coast Mountains of British Columbia through the Cascades and Sierra Nevada, as far south as the headwaters of the Kern River overlooking the Owens Valley, CA. There are outliers in the Warner and Siskiyou Mountains, CA (Critchfield and Little 1966).

Pinus cembra is usually regarded as alpine in distribution, because its most famous stands are in Switzerland, Austria, France, and the Dolomitiche and Bergamasche Alpi of Italy. But there is a *cembra* presence in extreme northwestern Yugoslavia, and there are significant populations farther east in the Carpathians. These include stands in the High Tatra of Poland and Czechoslovakia, and an archipelago-like scattering of stands in the Gorgany Mountains of the Ukrainian SSR and in several

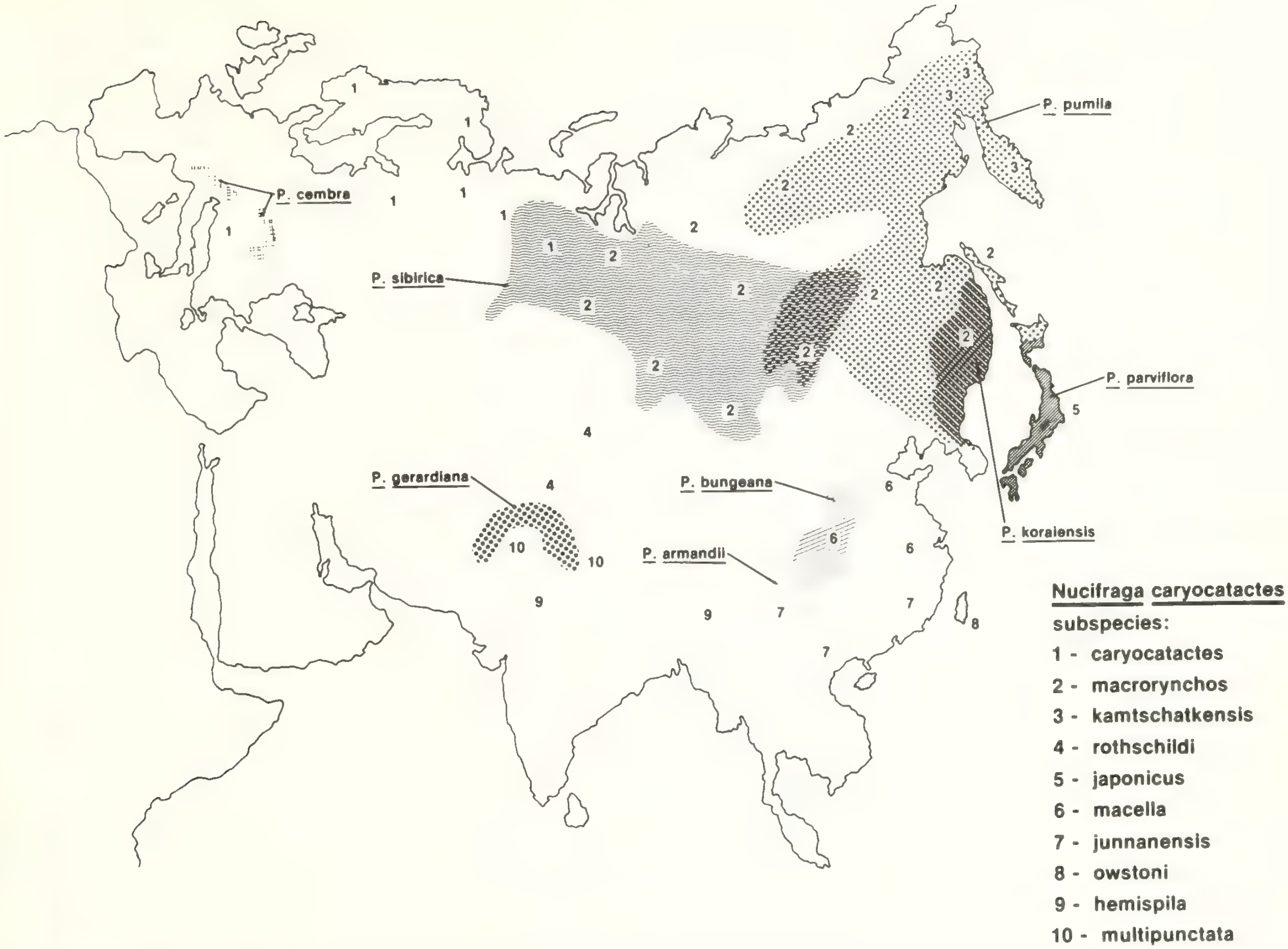

Figure 7—Geographic ranges of Eurasian wingless-seeded and nearly-wingless-seeded *Strobus* pines (after Critchfield and Little 1966) and subspecies of the Eurasian nutcracker (after Dement'ev and others 1954).

mountain ranges in Romania's Carpatil Meridionali ("Transylvanian Alps"): the Rodnei, Calimanilor, Fagarasului, Busegi, Sebesului, Retezatului, and Banat (Myczkowski 1975).

Pinus koraiensis extends from around Sovetskaya Gavan' in southeastern Siberia (Primorskiy Kray) south along the east face of the Sikhote Alin mountains on the coast of the Sea of Japan, into North Korea, and westward into Manchuria (Kirin and Heilungkiang). There are outliers in high mountains of South Korea and in central Honshu and Shikoku in Japan (Critchfield and Little 1966; Hyun 1972).

Pinus pumila is the only pine of section *Strobus* found north of latitude 70° N, approaching to within about 100 km (60 mi) of the Arctic Ocean at the Kolyma River delta. It is also the farthest-ranging *Strobus* pine, and is exceeded in this respect among pines only by *P. sylvestris*. Its range includes the coast of the far eastern USSR from about Khatyrka on the Bering Sea, around the Kamchatka Peninsula along the Sea of Okhotsk, and south along the Sea of Japan nearly to Vladivostok. Inland it ranges across eastern Siberia to the Lena River and Lake Baikal, even entering Mongolia. It is in the Kurile Islands, Sakhalin, and south through Hokkaido and Honshu to just south of Tokyo. There are outliers in North Korea and Manchuria (Critchfield and Little 1966; Saho 1972).

Pinus sibirica extends from the Urals and western Siberia east across the Central Siberian Plateau to the Aldanskoye Upland. It occurs widely in northern Mongolia from Lake Uvs east to Uuldza. It grows throughout the Altai Territory and Eastern and Western Sayans of Krasnoyarsk Territory, in the Irkutsk region and the Transbaikal. There are outliers on the Kola Peninsula near Murmansk, about 1,000 km (600 mi) from the main range in the northern Urals (Critchfield and Little 1966).

An aspect of stone pine geography that may be worthy of attention is that of range overlap with other wingless-seeded pines. If species are sympatric, and if their cone

crops do not fail in the same years, then avian seed dispersers would be insulated against seed-crop failure in either species. For example, the Rocky Mountain range of *albicaulis* is often paralleled at lower elevations by that of the wingless-seeded *flexilis*. In years when *albicaulis* in Togwotee Pass, WY, has borne no cones, I have seen large flocks of nutcrackers foraging among *flexilis* trees in woodlands within 10 km (6 mi) and beyond. Though it has not been shown that the same birds feed alternately upon the two pines, the availability of both within the reach of a mobile bird species strongly suggests so. Vander Wall (1988) has recently shown how nutcrackers utilize two wingless-seeded pine species in similar circumstances. *Pinus monophylla*'s range, at the east foot of the Sierra Nevada, also parallels, at lower elevations, that of *albicaulis*. Tomback (1978) has described how nutcrackers forage on both species as well as the winged-but-large-seeded *P. jeffreyi* that grows with *albicaulis*.

Pinus koraiensis and *pumila* are in close proximity in the Primorskiy region of southeast Siberia: *koraiensis* is along the coast and lower slopes, and in interior valleys, while *pumila* is in the higher regions. In central Honshu, Japan, the community type in which *koraiensis* was found had a characteristic elevation of 2,080 m (6,900 ft), while *pumila* scrub occupied elevations over 2,400 m (7,900 ft) (Franklin and others 1980).

Pinus pumila is also widely sympatric with *sibirica* in a huge area—about the size of the Scandinavian Peninsula—surrounding Lake Baikal and extending northeast to the Aldan and Stanovoy Mountains. High-elevation forms of *sibirica* have been reported from the Altai, the Sayans, northern Mongolia, and the Transbaikal region. They include *P. sibirica* f. *humistrata* (Middendorf) Novac, f. *coronans* (Litv.) Krylov, f. *depressa* Kom., and f. *turfosa* Gorodkov (Pravdin 1963). Pravdin (1963) pointed out that the recognition of these "forms" may reflect an interest in plants growing in bogs and on high mountains, and that proper study of intraspecific variation in *sibirica* has been lacking.

Pinus cembra alone among the *Cembrae* pines is not sympatric with any other wingless-seeded *Strobus* pine. In none of the cases of sympatry cited here has there been an indication of interspecific hybridization.

It seems noteworthy that a very hungry nutcracker could, theoretically, eat its way through nearly 6,400 km (4,000 mi) of stone pines from Chelyabinsk to the Bering Sea! While such an event may have a low probability, it does focus the mind on the immensity of the nutcracker-established stone pine forest of northern Asia; and the general lack of appreciation of the ubiquity of the pine-corvid mutualism.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from R. H. Smith)—Do you think "buried" seeds germinate and survive better than wind-disseminated seeds? Therefore, is the winglessness actually an advantage to stone pines?

A.—However a seed is disseminated, it is most likely to germinate successfully if it is covered with soil. Small winged seeds may frequently find themselves wedged into tiny cavities in the soil microtopography, large seeds less frequently unless animals put them in the soil. Obviously both systems work well enough.

Q. (from Earle F. Layser)—Bristlecone pine has a winged seed. It is widely dispersed on mountain tops, crags, etc. in the Southern Rockies. Why does it seem to have a similar pattern as stone pine in its occurrence at high elevation (obviously not strictly wind dispersed)?

A.—Great Basin bristlecone, though it has a small, winged seed, is indeed often dispersed and established by Clark's nutcracker at high elevations. See my recent article in Arctic and Alpine Research 20: 358-362, August 1988.

Q. (from Doug Turner)—Do pine seeds undergo any needed changes while in the crops of nutcrackers or are the seeds able to germinate if humans plant them? Any speculation or evidence of why nutcrackers fly so far to cache in burns if they can successfully cache under unburned canopies?

A.—No changes are known to occur to seeds while they are in the nutcracker's pouch. Sometimes the seeds are there for only a few minutes. We urgently need more information on nutcracker behavior, so until we get it you will have to either guess at their motives or ask them about it.

Q. (from Tad Weaver)—In tree islands, what comes first - *Pinus* or *Abies*? What's your evidence?

A.—My only experience is with establishment of groves in Squaw Basin, WY. Here Karen Snethen (1980) found whitebark pine pioneering on moraines, and Engelmann spruce later coming in under the pines. See her master's thesis for evidence in the form of chronosequences.

DISTURBANCE AND MANAGEMENT PROBLEMS IN LARCH-CEMBRA PINE FORESTS IN EUROPE

Friedrich-Karl Holtmeier

ABSTRACT

Cembra pine (Pinus cembra) *and larch* (Larix decidua) *form the uppermost forests in the Central Alps. Due to human influences, the timberline became lower and the species composition and structure of these forests changed. In general they are over-aged. As a consequence of the modern decline of pasturing, the natural succession from larch to cembra pine forest has been revived. In places it may be hampered by the larch bud moth, which may kill young cembra pines in the understory. Abandoned alpine pastures are invaded mainly by cembra pines. The larch-cembra pine forest as well as high-altitude afforestations and the invading cembra pines must be managed with the objective to restore the climatic timberline and to produce well-structured forests.*

INTRODUCTION

In Europe cembra pine (*Pinus cembra*), which is closely related to whitebark pine (*Pinus albicaulis*), is common only in the Alps (fig. 1). In the Tatra and southern Carpathian Mountains, cembra pine is restricted in occurrence. Therefore, this paper focuses on the Alps.

The Alps extend from west to east for about 1,000 km (746 mi). Their width ranges between 150 km (93.2 mi) in the west to about 250 km (155 mi) in the middle and eastern parts. The Alps are deeply dissected and characterized by rugged topography. The mountain rim is exposed to moisture-carrying air currents from northern, western, and southern directions. Thus, the climate of the outer ranges is rather maritime compared with the Central Alps, which are sheltered from these maritime influences (fig. 2).

Consequently, the upper timberline occurs from about 1,600 to 1,800 m (4,980 to 5,906 ft) in the outer ranges and from 2,200 to 2,400 m (7,218 to 7,873 ft) in the central region. In the outer mountains the montane and subalpine forests are dominated by spruce (*Picea abies*) and in places by beech (*Fagus sylvatica*), while cembra pine is found there only as relict stands in the upper subalpine belt and at the upper forest limit. Above the subalpine spruce forest occurs a more or less unbroken belt of prostrate mountain pine (*Pinus mugo*). This mountain pine belt is quite different from the krummholz belt in the high mountains of the western United States, because the prostrate growth form of *P. mugo* is genetically predetermined and not the result of the actual climatic environment (Holtmeier 1973, 1981).

In the Central Alps, the uppermost forests are formed by cembra pine and European larch (*Larix decidua*); spruce is common only at lower elevations. In general the range of cembra pine does not extend below 1,700 m (5,577 ft), because the species cannot successfully compete with spruce. Cembra pine is almost excluded from the outer ranges, which are characterized by heavy snow fall and long melting periods, because it is highly susceptible to snow fungi infections.

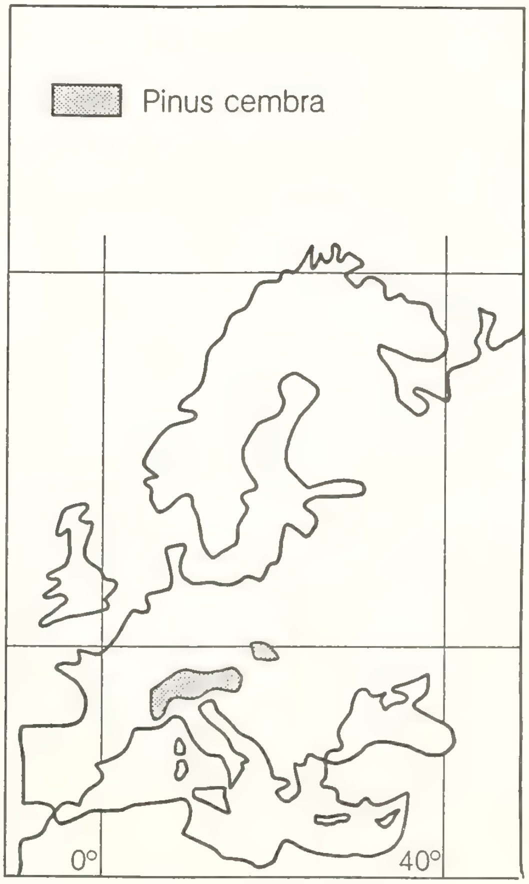

Figure 1—Distribution of cembra pine (*Pinus cembra*) in Europe.

Paper presented at the Symposium on Whitebark Pine Ecosystems: Ecology and Management of a High-Mountain Resource, Bozeman, MT, March 29-31, 1989.

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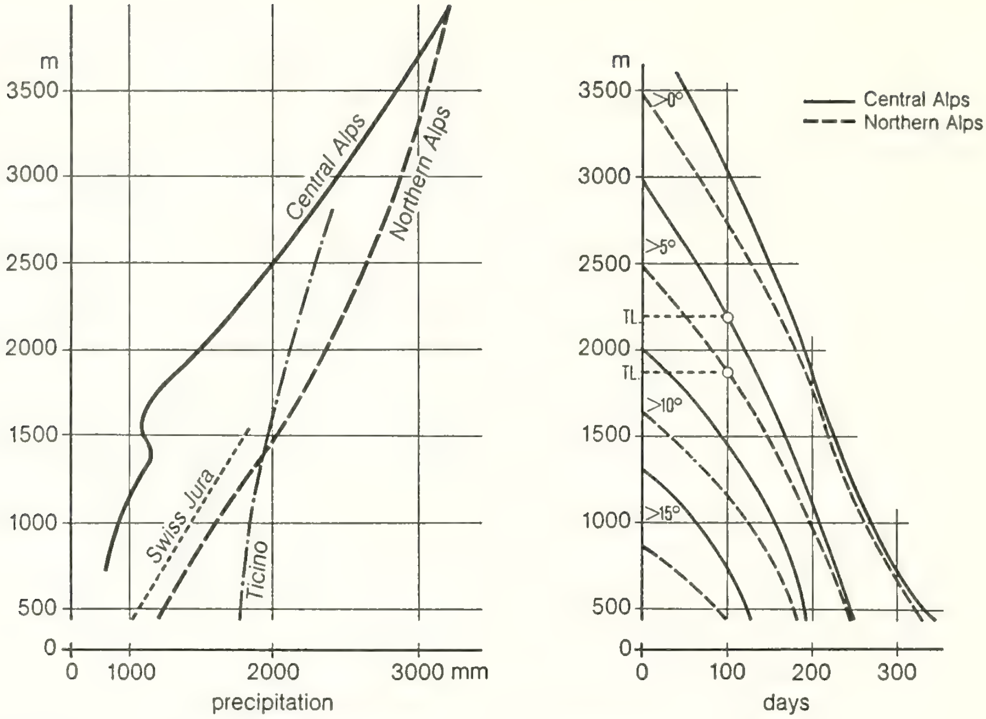

Figure 2—Annual amount of precipitation (left) and number of days with mean temperatures above 0, 5, 10, and 15 °C (right) in the Central Alps and in the outer ranges (after Ellenberg 1978).

Following Pleistocene glaciation, dissemination of seeds by the European thickbilled nutcracker (*Nucifraga caryocatactes caryocatactes*) (fig. 3) probably enabled cembra pine to spread from its refugial areas in the lowlands close to the southern Alps and the Carpathian Mountains and quickly resettle the high mountains. Some good evidence suggests that cembra pine spread faster than spruce (Mattes 1978, 1982).

There is no mountain pine belt above the larch-cembra pine forests. Mountain pine and green alder (*Alnus viridis*), which is another true krummholz species, are confined to avalanche tracks and similar sites unsuitable to upright tree growth.

The Alps, like many other high-mountain regions of Eurasia, were already settled in prehistoric time, which means there was persistent use of the mountain forests throughout history. Many of the forests were heavily grazed or cleared for agriculture and alpine pastures. Others were destroyed by ore mining, salt works, and charcoal production, especially during the Middle Ages. Overgrazing of the alpine vegetation caused severe soil erosion, which also was harmful to the subalpine forest below. As a consequence of these activities, not only did the upper timberline become lower, but also the species composition and structure of the mountain forests changed considerably. In many central alpine valleys, larch could spread at the cost of cembra pine. The situation in the Upper Engadine serves as a good example of human history and ecological changes in the Central Alps.

Figure 3—European thickbilled nutcracker at a winter feeding place.

THE UPPER ENGADINE FORESTS

The Upper Engadine is located in the eastern part of Switzerland and comprises the uppermost drainage area of the Inn River. The bottom of the main valley is situated at an altitude of 1,700 to 1,800 m (5,185 to 6,300 ft); the tributary valleys climb up to 2,300 m (7,546 ft). The highest peaks' elevations are about 4,000 m (13,123 ft).

Due to the geographical location and the high mass-elevation of the Engadine, the climate is rather continental. Although lowered by human disturbances by about 150 to 300 m (492 to 984 ft), the upper limit of the larch-cembra pine forest is located at about 2,200 to 2,300 m (7,217 to 7,546 ft) at places. Solitary crippled trees may still be found at and even above 2,500 m (8,202 ft) (Holtmeier 1965, 1967).

Distribution Patterns

The Engadine larch-cembra pine forests belong to the so-called silicate type (*Larici-Cembretum*, Ellenberg 1978; *Larici Pinetum cembrae*, Oberdorfer 1970), which is common to the crystalline Central Alps. Depending on the local site conditions, the forests display subtypes that can be distinguished by the different plant communities of the understory vegetation (grasses, dwarf shrubs). Thus, the uppermost cembra pine forests, which are relatively open, are characterized by *Rhododendron ferrugineum* and *Vaccinium myrtillus* (*Larici-Cembretum rhododendretosum ferruginei*) (fig. 4). Cembra pine regenerates vigorously there if not destroyed by red deer or livestock. Larch seedlings are very rare. The soil is a Ferro Orthic

Figure 4—Open larch-cembra pine forest with dwarf shrubs (*Rhododendron ferrugineum, Vaccinium myrtillus*) as understory vegetation. Upper Engadine, northwest-facing slope of the main valley at 2,200 m (6,710 ft).

Figure 5—Cembra pine regenerates successfully in the dwarf shrub vegetation (background) but is almost excluded by *Calamagrostis villosa* (foreground). God da la Stretta, 1,830 m (5,582 ft). Photo by H. Mattes.

Podzol (FAO terminology), characterized by a thick, raw humus layer with high moisture capacity. In the forests below 2,000 m (6,562 ft), *Calamagrostis villosa* may dominate the undergrowth, especially if the crown cover lets the sunlight pass to the forest floor. There, *Rhododendron, Vaccinium*, and other dwarf shrubs are often outcompeted and replaced by warmth- and light-demanding species. However, the dense grass cover especially *Calamagrostis villosa*, not only hampers the regeneration of larch, but of cembra pine also (fig. 5).

In general, cembra pine is found on steep, rocky, and inaccessible slopes and north exposures. Although usually mixed with larch, it also forms pure stands. Larch prevails in easily accessible locations with southern exposures and on gentle foothills at the base of the steep walls of glacially molded valleys (figs. 6, 7). There we find extensive pure larch forests. The distribution patterns of larch and cembra pine are entirely due to human disturbances (Auer 1947; Holtmeier 1967).

Figure 6—Distribution pattern of cembra pine and larch. Pure larch forest covered the valley bottom and the talus cones at the base of the steep walls of this glacially molded valley. Pure cembra pine stands are confined to rocky, inaccessible sites. Roseg Valley, view to southwest.

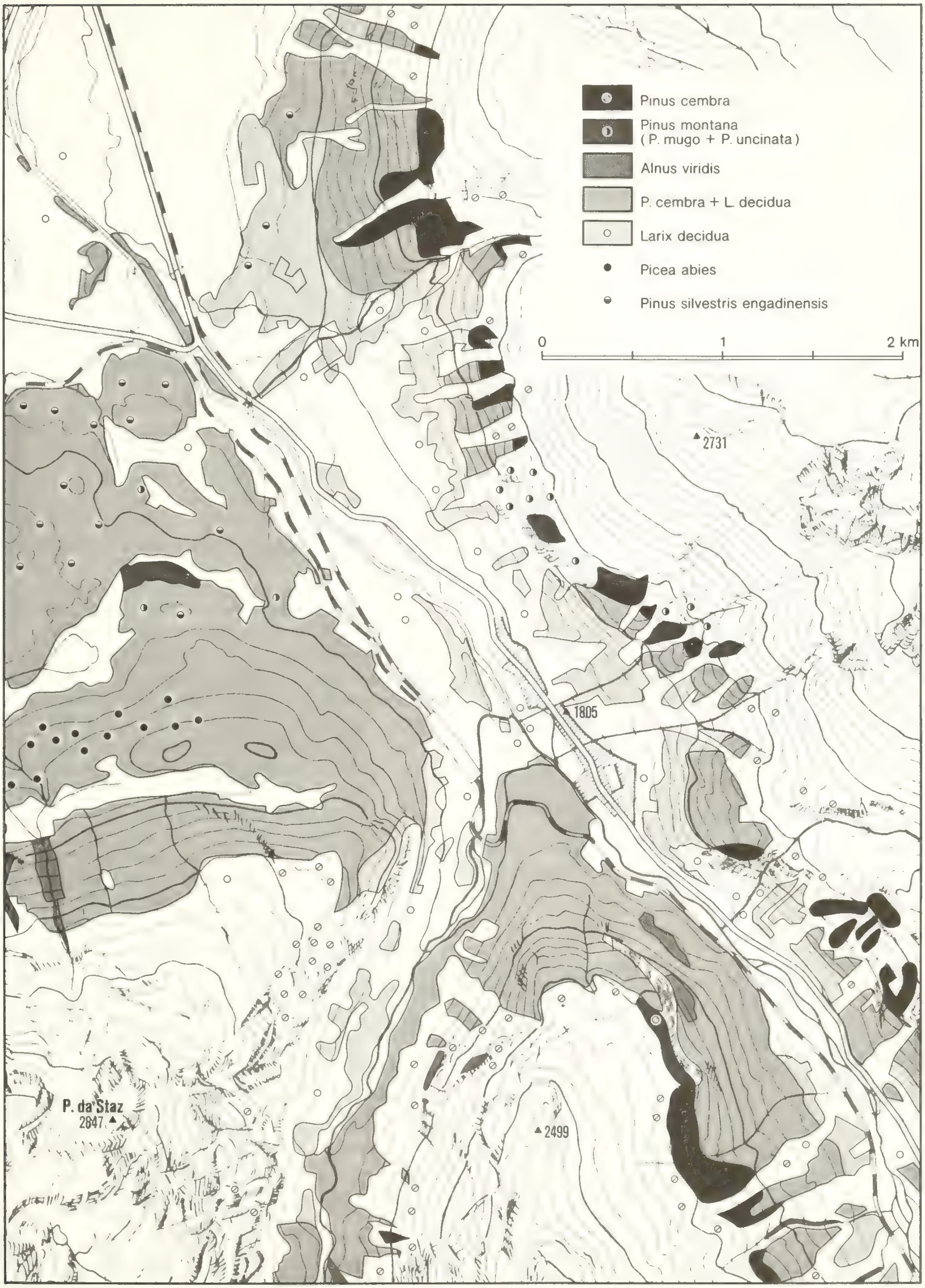

Figure 7—Distribution of the tree species in the Bernina Valley, Upper Engadine.

Under natural conditions larch, which is a shade-intolerant species, prevails in the pioneer stages of forest succession and then is gradually replaced by cembra pine. Cembra pine is more shade-tolerant, and because of its heavy, energy-rich seeds, regenerates successfully, even in thick, raw humus and dense plant cover. Thus, pure larch stands are expected only on screes, boulder fans, talus cones, and similar sites rich in bare mineral soil and lacking dense grass, dwarf shrubs, or both.

However, although cembra pine can be regarded as typical of advanced successional stages of forest development, it may also occur as a pioneer species on bare boulder fields, on moraines, or in front of retreating glaciers (fig. 8).

Disturbances

Cembra pine not only hampers the regeneration of larch, but it also prevents the growth of herbs and grasses on the forest floor because of its dark, shade-giving crown and slowly decaying needle litter. As a result, the cembra pine was systematically eliminated by people on sites suitable for grazing and restricted to inaccessible sites and northern exposures (figs. 6, 7). In addition, its soft wood was used for different purposes, such as wood carving, construction of wood trunks, furniture, and artifacts. Also, cembra pine suffered more from burning than deciduous larch, which is protected by thick, cork-like bark and may refoliate after burning. Finally, larch was favored by grazing, because the plant cover was frequently destroyed by trampling; thus, a suitable seedbed (exposed mineral soil) was provided.

Cyclic mass outbreaks of the larch bud moth (*Zeiraphera diniana*), which nowdays occur at intervals of 8 to 9 years, have been intensified by the expansion of the larch forests. These outbreaks very seldom kill larches, because they are able to refoliate. However, young cembra pines in the understory may be destroyed when the larvae leave the defoliated larch crowns to feed on cembra pine needles

Figure 8—Pioneer cembra pines invading the lateral moraine of the Morteratsch Glacier (Upper Engadine). Elevation 2,100 m (7,350 ft).

Figure 9—Cembra pines invading an ungrazed larch forest (2,000 m; 6,100 ft).

(Baltensweiler 1975; Campell 1955). Thus, the natural succession might have been retarded. Most of the former pasture forests have become completely over-aged (fig. 4).

As a consequence of modern changes in the economic structure of the alpine regions, human activities today are quite different than those of the past. Tourism has become the main base of existence. Thus, the use of forest pastures and alpine pastures has declined. In many places the natural succession from larch to cembra pine forest, which had been interrupted by humans for hundreds of years, is going on again.

Though cembra pine produces good cone crops only periodically, there are always enough viable seeds for effective regeneration. The seeds are spread by squirrels (*Sciurus vulgaris*) and other rodents such as the common vole (*Microtus arvalis*), bank vole (*Clethrionomys glareolus*), by woodpeckers (*Dendrocopus major*), willow tits (*Parus montanus*), nuthatches (*Sitta europaea*), and by the European nutcracker into the former pasture-forests (Mattes 1985). Although these animals feed on the seeds, abundant quantities are left to guarantee vigorous regeneration of cembra pine. Dense groves of cembra pines have grown up below the canopy of the ungrazed larch forest (fig. 9).

However, this process may be slowed by damage caused to the terminal shoots and needles of the young cembra pines in the understory by the caterpillars of the larch bud moth and by secondary parasites such as different kinds of beetles (for example, *Pissodes pinii, Pityogenes bistridentatus, Pityophterus knotecki, Ips amitius*). Thus, the trees may become crippled or killed. In general, cembra pines shorter than 5 m (15.25 ft) are most seriously injured (Baltensweiler and Rubli 1984). The mass outbreaks of the larch bud moth seem to be more harmful to young cembra pines than to mature larch trees. Nevertheless, high proportions of larch can only be maintained by removal of the dense grass and dwarf shrub vegetation on the forest floor and by exposing the mineral soil. Otherwise, in the long run, larch is going to be replaced by cembra pine on most sites.

Natural Reforestation of Alpine Pastures

Just as conspicuous as the revived succession in the larch-cembra pine forest is the invasion of abandoned or rarely grazed alpine pastures. Surprisingly, it is cembra pine, not larch, that is most successful in resettling these areas (Holtmeier 1965, 1967). This is primarily caused by the dense grass and dwarf shrub vegetation that prevents the light larch seeds from reaching a suitable seed bed. Seeds of cembra pine are approximately 90 times heavier than larch seeds (Auer 1947).

The heavy, wingless seeds of cembra pine (fig. 10) are chiefly spread by the European nutcracker, which places food caches of nuts in the soil, rotten trunks, and in other suitable places, particularly at sites on small ridges, spurs, knobs, and rocky outcrops (Holtmeier 1966; Mattes 1978, 1982). Thus, the distribution of cembra pine depends more on the nutcracker's home range or area of activity than on the distance from the seed trees in the subalpine forest. In contrast, the occurrence of larch seedlings declines rapidly with increasing distance from the mother tree, as is characteristic of windborne tree seeds (Holtmeier 1974; Kuoch 1965).

Many of the seeds hoarded by nutcrackers remain unused and thus may give rise to cembra pine seedling clusters (fig. 11). Almost no cached cembra pine nuts are lost to mice. Above the timberline only the common vole (*Microtus arvalis*) is common at places. However, the common vole prefers dense plant communities such as *Deschampsia* meadows, which provide sufficient protection from predators. The nutcracker does not establish seed caches in these plant communities (Mattes 1978, 1982).

It is not only the distribution of seeds over relatively great distances, but also the specific choice of locations or the food caches that makes the nutcracker and cembra pine an important factor in natural high-altitude reforestation. This must be viewed in relation to the drastic environmental change that took place when the uppermost forest belt was destroyed by humans in the past. Above the closed forest, tree growth is impeded more by unfavorable site conditions than one would expect at the present level of the timberline. When the forest was removed, the windflow near the soil surface and the amount of solar radiation became strongly influenced by the local topography.

Sites vary in their exposure to solar radiation, wind velocity and directions, height and duration of the snow cover, length of the growing season, distribution of the soil temperature, soil moisture, and other factors. At present, sites relatively favorable to tree growth are near sites without trees. At exposed sites, which lack snow cover or are only occasionally covered with snow in winter, young trees suffer from desiccation, frost damage, and ice particle abrasion (fig. 12). On leeward slopes and in other places characterized by heavy snow accumulation, the growing season may be too short and evergreen conifers such as cembra pine are heavily damaged or even killed by snow fungi (for example, *Herpotrichia juniperi, H. coulteri, Phacidium infestans, Lophodermium pinastri*). In addition, thick, raw humus layers, typical of cool and moist north-facing sites, may prevent germination of seeds and growth of seedlings. And finally, the mycorrhizal flora was reduced by past disturbance and thus nutrient uptake by the seedlings may be considerably hampered. Even in the long-term, successful natural restocking will be confined to the favorable localities.

The sites chosen by the nutcracker for its food caches appear to be relatively favorable to successful growth of seedlings and saplings. Furthermore, the distribution of young cembra pines in tree clusters is advantageous

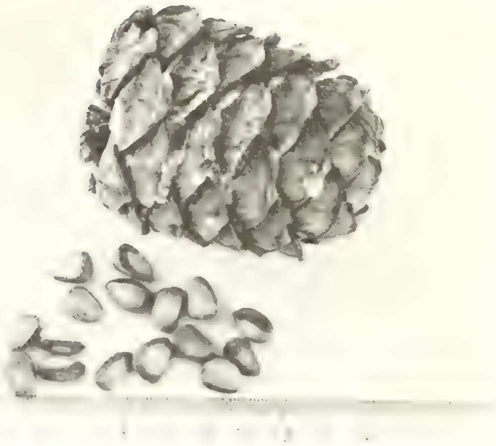

Figure 10—Cone and seeds of cembra pine.

Figure 11—Cembra pines that rose from a nutcracker's seed cache. Muottas da Celerina, Upper Engadine, at about 2,250 m (6,883 ft).

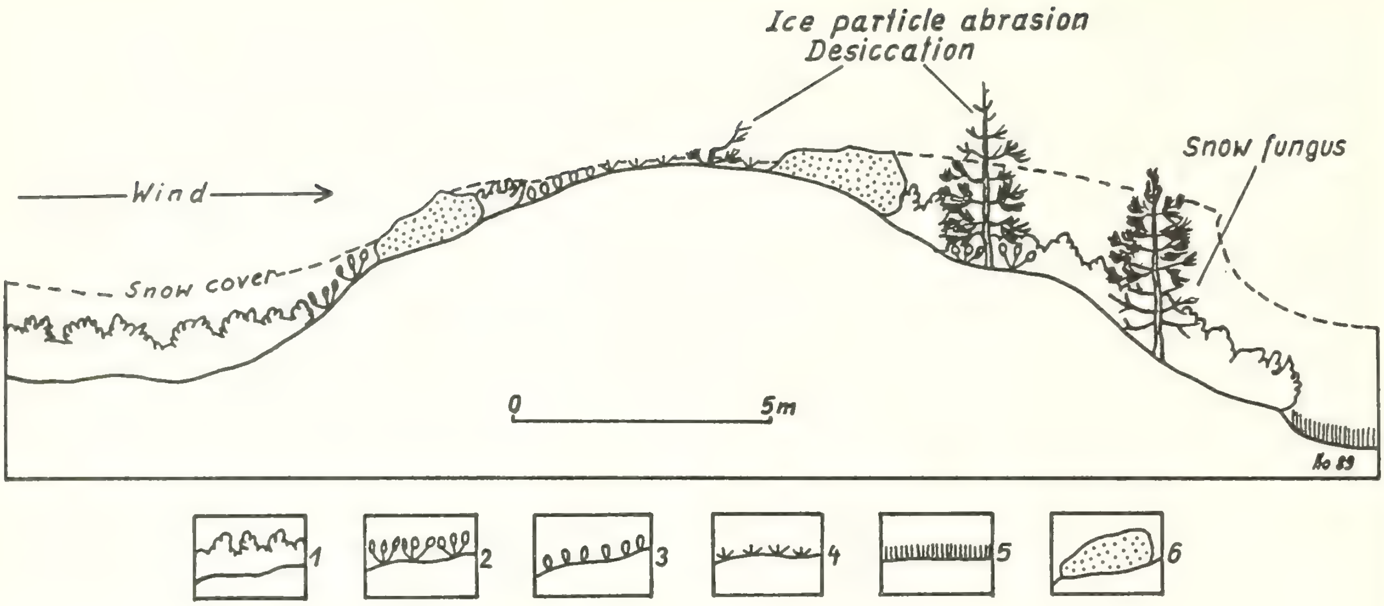

Figure 12—Influence of wind and snow cover on the distribution of ground vegetation and on young cembra pines in abandoned alpine pastures (schematic, following the conditions on the northwest-facing slope of the upper Engadine main valley (Holtmeier 1965, 1971)). (1) *Rhododendron ferrugineum*; (2) *Vaccinium myrtillus*; (3) *Vaccinium uliginosum, Empetrum nigrum*; (4) *Loiseleuria procumbens*, lichens (*Alectoria ochroleuca, Thamnolia vermicularis, Cladonia* spp.), *Juncus trifidus*; (5) *Trichophorum caespitosum, Eriopherum scheuchzeri, Carex* spp.; (6) boulder.

to those saplings growing up in the center of the clusters. Those trees are fairly well protected by the outer saplings from injurious climatic influences such as desiccation and ice blast—at least for a while. Nevertheless, as time goes on, many of the trees will succumb to root competition and also to snow fungi.

Fungi infections often become a detriment to cembra pines even on sites exposed to wind that, previous to seedling establishment, had little snow cover in winter (fig. 13). As seedlings grow taller, they begin to influence local windflow, and as a result snow accumulations near the soil surface (fig. 14). Thus, more snow will be accumulated within the tree clusters, and the duration of the snow cover may increase greatly.

The invasion of former alpine pastures, especially by cembra pine, cannot be compared to the invasion of natural subalpine meadows by trees in many mountain ranges in the western United States. The changes in the Alps are caused by cessation of disturbances; the changes in montane North America may be the result of more favorable climatic conditions.

Figure 13—Cembra pines planted by the nutcracker above the closed forest on the northwest-facing slope of the Upper Engadine main valley at 2,270 m (6,924 ft). The lower needles have been destroyed by *Phacidium infestans* after tree growth resulted in increased snow accumulations.

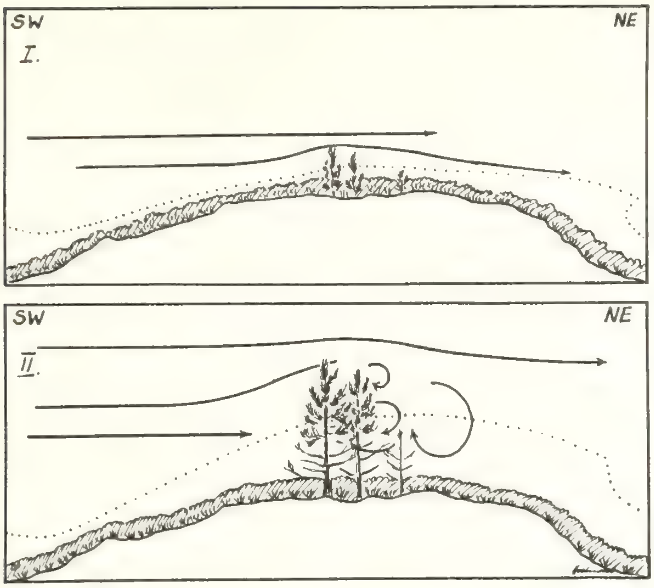

Figure 14—Influence of growth of cembra pines on windflow and snow accumulation.

MANAGEMENT OF THE LARCH-CEMBRA PINE FORESTS

It is clear that in the Engadine, as in the Alps in general, no forests remained untouched by humans. The use of the land has completely changed in modern times, but the legacy of disturbance and deforestation still has profound effects. Due to the extensive deforestation and over-utilization of the remaining forests, natural catastrophies such as avalanches, torrential floods, soil erosion, and land slides have increased and become a permanent threat to the people living in the mountain valleys. About 60 percent of the avalanches, for example, are released within the deforested area above the timberline. Maintenance of the remnant forests by careful silvicultural treatment and reforestation up to the climatic limit of tree growth, combined with fence construction when necessary, have proved to be the best way to reduce such catastrophies.

The first efforts to restore the uppermost forests were made about 130 years ago. Many of these early high-altitude afforestations failed completely because the environmental conditions, such as local climate, soil, and plant competition, had not been understood. However, it is evident that it is insufficient to protect the existing critical forests from commercial timber harvesting and to reforest the mountain slopes as high as possible. The forests should be managed to produce natural forest structure (age classes, density, coverage, etc.) and a variety of successional stages (Campell 1955; Mayer 1979).

In practice, opinions concerning specific silvicultural methods may differ considerably and recommendations can only be given with regard to the local situation. In the upper subalpine forests in the Engadine, cembra pine must be treated as part of the larch-cembra pine forest ecosystem. Natural succession in the ecosystem depends on the competition between cembra pine and larch.

For practical reasons, it seems appropriate to first look at the contiguous forest and then at the reforestation above the contemporary human-caused timberline. On the level foothills at the bottom of the glacial valleys and on the lower, sun-exposed slopes where open, over-mature larch forests still prevail, the cyclic mass outbreaks of the larch bud moth cause the most serious problems in developing a well-structured and healthy forest. Direct control of the larch bud moth with insecticides and bacteria has proved unsatisfactory. Also, there is increasing opposition by the public to chemical control. The best result could probably be achieved by appropriate silvicultural management (Baltensweiler 1975; Baltensweiler and Rubli 1984).

Thus, at sites not threatened by avalanches, high stem density and a rotation age of 150 to 200 years could reduce forest damage, because the larch bud moth populations grow most quickly in over-aged, open, and warm larch forests. Additionally, larch should be controlled for the benefit of cembra pine. Since the growth of cembra pine in the understory of the larch forests may be impeded by the larvae of the larch bud moth, a mixed forest, which consists of stands of pure larch and stands of cembra pine, might be most successful.

Most of the uppermost forests are over-mature, open, and consequently very sensitive to disturbances by windthrow, avalanches, and snow slides. Due to the short growing season, trees grow very slowly, and only occasional regeneration occurs. Luxuriously growing dwarf-shrubs and grasses hamper not only the natural regeneration of larch, but also of cembra pine. Big snow masses accumulate within the scattered tree stands. In clearings less wide than the height of the surrounding trees, the energy balance becomes negative because the incoming solar radiation is intercepted by the trees while the loss of out-going, long-wave radiation is almost unimpeded. Increased snow accumulation and negative energy balance result in delayed snow melt. Thus, scattered seedlings and saplings of cembra pine are more often damaged by snow fungi than trees in dense forests that offer more protection against snow (fig. 15). Consequently, the objective of silvicultural management must be to improve conditions for the regeneration of larch, which does not suffer from snow fungi. If necessary, the dense ground vegetation should be removed to provide suitable seed beds. In addition, larch should be planted. In the course of time the deposition of snow will be reduced by the closing crown cover. Thus, cembra pines in the understory, less threatened by snow fungi, could better survive.

To minimize the risk of disturbance and simultaneous decay of over-mature forests, a great variety of successional stages should be produced by silvicultural measures. Ongoing regeneration of larch trees, for example, can only be maintained if the bare mineral soil is exposed within the forest openings.

Figure 15—Young cembra pine that lost almost half of its needle foliage (circled) by *Phacidium infestans* activity. Morteratsch Valley, Upper Engadine at 2,170 m (6,618 ft).

It has become obvious that cembra pine and larch are the species most appropriate for high-altitude afforestation in the Alps. Within plantations at timberline level in the Dischma Valley (west of the Engadine), after 8 years the survival rate was 71 percent for cembra pine and 81 percent for larch. Only 59 percent of mountain pine survived (Schönenberger 1985). The lower survival rate of cembra pine compared to larch was due to increasing fungi infections. Dense groups of 50 to 100 cembra pine trees should be planted. The distance between the individuals should not exceed 50 to 100 cm (1.6 to 3.2 ft). The groups should be separated by glades 6 to 8 m (19.7 to 24.3 ft) wide (Schönenberger 1986). This distribution will favor the accumulation of snow within the glades, thus keeping the risk of fungi infections low in the tree groups. However, reports from the Dischma Valley study site stated that adult cembra pines on wind-exposed spurs were heavily infected by *Phacidium infestans*. Two other fungi, *Ascocalyx abietina* and *Scleroderris lagerbergii*, seem to have become increasingly injurious to cembra pine during the last 20 years. Damages caused by *Ascocalyx* are most common on cool and moist north-facing sites and in gullies with late-melting snow cover (Schönenberger 1985).

Large populations of game animals and continued livestock grazing are other threats to forest regeneration. Cembra pine is very sensitive to browsing and trampling by red deer (*Cervus elaphus*) and livestock (fig. 16). Sheep, especially, are a most detrimental factor. Larch may more easily recover from damages caused by browsing animals. Winter feeding has reduced annual losses of red deer by starvation, resulting in unnaturally large populations. This never would have been possible in an undisturbed natural environment. Thus, all kinds of grazing should be excluded from the forest and areas that are being invaded by trees.

The ongoing natural invasion of abandoned alpine pastures, especially by cembra pine, should be aided by management. This process will not succeed without help, because only a continuous compact, uneven-aged forest belt reaching as high as possible provides sufficient protection. Thus, in many areas the forest must be brought back by active management. However, the disturbance-caused lower timberline has become as formidable an ecological barrier as the natural climatic timberline had been before (Holtmeier 1965, 1974, 1987). Consequently, reforestation has to be carried out with respect to the local site patterns. That means excluding all sites from afforestation that are unfavorable to tree growth at the beginning of the effort—sites characterized by low solar radiation, low soil temperature, and long-lasting snow cover. If necessary, afforestation must be combined with artificial constructions such as avalanche walls and snow fences.

Figure 16—Young cembra pines damaged by livestock, 2,200 m (6,715 ft).

CONCLUDING REMARKS

I will leave it at that. The history of the high-altitude forest has roughly been outlined with special reference to cembra pine's ecology and role in the successional development of the forest. Disturbances and management problems of cembra pine in the larch-cembra pine forests of the Engadine have been discussed. It is obvious that the present ecological situation of cembra pine can be understood only if the numerous historical human influences on the forest ecosystem are considered. It is also evident that the situation in the Alps is quite different from that of most of the high-mountain forests of the western United States, where the first serious human influences do not date back more than 200 years.

The larch-cembra pine forests are now avalanche-protection forests, almost without exception. Thus, cembra pine must be managed to restore the climatic timberline and to produce well-structured, healthy forests to ensure their long-term vitality and protective function (fig. 17).

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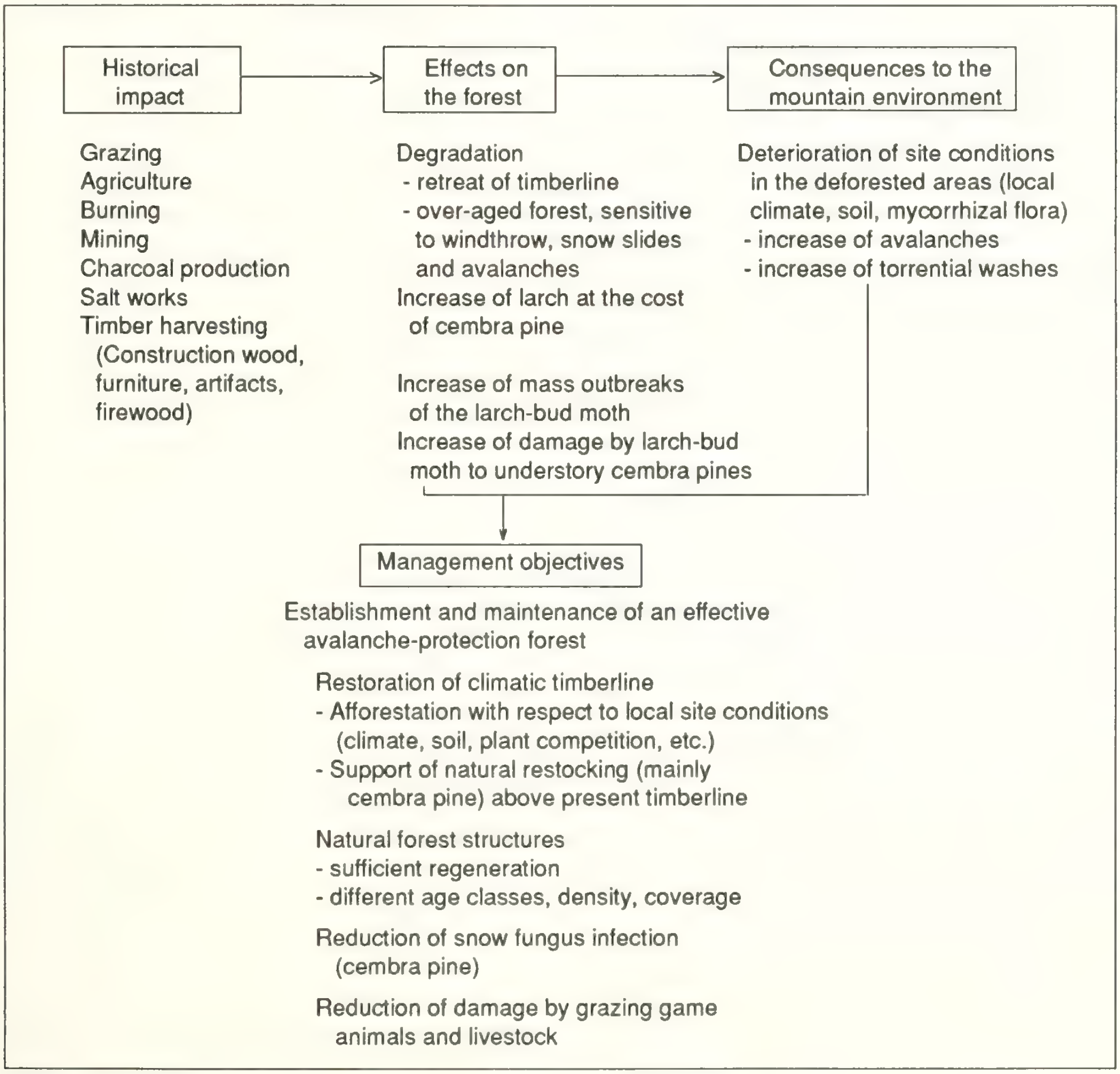

Figure 17—Synopses of human impacts, effects, and management possibilities to restore the larch-cembra pine timberline and maintain a healthy forest.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from Richard G. Krebill)—Is *Pinus cembra* as heavily damaged by the blister rust as is *Pinus strobus*?

A.—There is almost no damage by the blister rust to *Pinus cembra*, which seems to be very resistant.

Q. (from Ward W. McCaughey)—Do larch and cembra pine grow as well in mixed as in pure stands? Does cembra pine, growing in pure stands, develop a straight bole?

A.—Larch and cembra pine grow as well in mixed as in pure stands. That depends on the site conditions and the human interferences described in my paper. Pure stands of cembra pine are normally found on steep, rocky, and inaccessible slopes. Larch prevails on gentle terrain, exposed to the south, and easily accessible where cembra pine was eliminated by humans.

The bole appearance depends to a great extent on the age of the trees and on site conditions. In dense stands straight boles may prevail. However, trees that originated from seed caches of nutcrackers are usually multistemmed. Very old trees display a candelabrum-like growth form.

THE FUTURE OF HIGH-MOUNTAIN BIOLOGICAL RESEARCH

Eldon W. Ross

ABSTRACT

The emerging importance of the Nation's high-mountain forests for nontimber uses, such as watershed, recreation, and wildlife, is discussed. Attention is focused on the fragility of these ecosystems and the need for silvicultural options to maintain their presence and values. The need to better understand these complex ecosystems through research is reviewed.

I appreciate the opportunity to join you at this unique meeting. It is my understanding that this may well be the first ecology and management meeting in the United States devoted solely to high-mountain resources. Your timing for such a meeting is very appropriate. Scientifically, these resources are not as well understood as other forest systems. For an array of reasons, we have not adequately explored the various silvicultural options available to use in managing high-mountain forests. But of even more importance is a lack of appreciation of the numerous values and benefits of high-mountain systems by both the general public and, to a lesser extent, by some land managers.

In the next few days, you will review what is known about selected ecosystems and individual forest types that characterize portions of western high-mountain forests. You will review their early history and some of the many factors shaping current stand structures. By the end of this meeting, you will have provided a basis for reexamining the information needs necessary for managing this complex resource in the future, and your information will provide a sound basis for maintaining the health of high-mountain forests.

High-mountain forests are not like the major forest types now under management at lower elevations. Some of the oldest living trees and stands are to be found in these forests. Yet this system is rather fragile. The reported decline in the spruce-fir forests of the Eastern United States and the high-elevation forests of Europe certainly suggests this fact. A slight shift in the degree of stress, be it caused by humans or natural, can accelerate the decline of such ecosystems. We may argue over the causes of these declines, but they are taking place. In the next few years, a number of major research initiatives will be directed toward establishing the relationship between environmental changes and forest conditions.

In both Europe and the United States, high-mountain forests are now considered mainly as multiple-use forest resources. Their real value lies not in traditional forest products, such as timber or fiber, but in their value as wildlife habitats, recreational areas, water resource management units, and as sensitive environmental indicators. The consequences of the various uses are not adequately known and attention must be paid to possible negative impacts on these ecosystems.

Their value as a major catchment for snow may well prove to be a prime reason for their careful management in the future. In the last few years, some areas of Europe had to relearn that high-mountain forests are a major source of protection from the massive movement of snow. Thus, their value as protection forests will determine the extent and type of management, if any, that will be applied.

As wildlife habitat, the mountain forests are somewhat unique. Their value as a wildlife habitat is well known to some but is still undervalued by many. During their different seasons, mountain forests provide an everchanging array of food sources as well as shelter. Many of the wildlife species spend only a portion of their time in these forests. Yet it is often a critical portion of time in terms of reproduction and maturation. How more intensive management and use, especially recreation, will impact on the maintenance of viable wildlife populations must be a priority research item. Strengthening management strategies for maintaining rare and endangered species that are associated with the high mountains must also receive additional attention. Some of these issues you will address in your section on animal interactions. Such research needs to be directed at an array of different mountain ecosystems.

With our highly mobile society and the apparent increasing desire for a broader array of recreational opportunities, we are beginning to experience wider use of high-mountain forests. People pressures will be manageable in wilderness areas. However, there are already demands to increase the number of ski slopes and some are now under construction in once untouched mountain forests. What will be the impact on the ecological stability of the remaining stands? What will be the impact on the protection value of reduced forest cover? These are research areas we must be willing to support now if we are to continue wise use. Lest you feel this is an academic subject, let me remind you of events in the Italian Alps in the last few years. The number of summer mudflows and snow avalanches has increased with expanded recreational development at higher elevations. Firm evidence is in hand that the ecological stability of the protection forest has been greatly reduced through thinning operations designed to create trails and additional ski slopes. Even

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in Europe with its relatively long history of mountain silviculture, I suspect much still remains to be learned. Yet, what is our current level of knowledge of appropriate European silvicultural practices that we could apply?

Finally, I would like to review briefly a viewpoint suggesting that high-mountain forests, because of their ecological sensitivity to their environment, are a barometer of climate change. Currently, a number of concerns exist in the scientific community and the general public. Those concerns include global warming caused by the rise in carbon dioxide levels from the use of fossil fuels as well as other gases—the so-called "Greenhouse Effect"—or the depletion of the ozone layer, which also contributes to a possible warming trend. We also have the presence of acid rain and related issues of pollution. To be sure, all of the facts related to these various issues are not available and we certainly can and will argue about what is really happening. Still, there are some indications that suggest we need to get on with focused research on sensitive ecosystems that will permit us to at least develop a rational level of understanding of what is happening. The first indication of forest decline was found in the high-mountain spruce-fir forests of Yugoslavia before it became apparent in lower elevations. To a degree, this also appears to be the case for the so-called spruce-fir forest decline in New England and decline in high-mountain forests of the Southeast. The causes for these forest declines are not known nor have current published research results completely clarified the situation. In West Germany, where the decline of European white fir and Norway spruce forests has received considerable attention, a review of earlier records suggests that in at least some forest regions, the declines were first apparent at higher elevations before they were detected in lower elevations. If we accept the premise that high-mountain ecosystems tend to be fragile and have limited elasticity to respond to change, then this early response to additional stress is not surprising.

If this concept that high-mountain forests are, in fact, a useful indicator of climate changes or environmental stresses, is correct then what type of research would prove useful? As noted earlier in this meeting, there are a number of descriptive ecological studies of at least the whitebark pine ecosystem. Certainly, we need a better understanding at the community level. This suggests the need to expand our studies to still other high-mountain systems and determine if there are some common ecological patterns. We need to strengthen our understanding of the genetic patterns of these systems, including the relative level of gene flow, if any, between related systems. Finally, I suspect that physiologically, high-mountain species will prove to be very different and interesting in their ability to respond to, and cope with, environmental changes. Research in Austria has for some time been focusing on certain aspects of comparative physiological studies of mountain species. Such research does suggest that high-mountain species do, in fact, have physiological coping mechanisms somewhat different from nonmountain species. How we can apply such information generally is not clear, nor have we adequately established the relationship of individual physiological responses to the interrelationships among competing species in a community. Mountain biological systems may be an ideal situation for establishing such relationships. Such complex questions clearly demonstrate the need to integrate the knowledge developed by different scientific disciplines.

There is great competition for research funding, but in establishing priorities for future programs we should not forget that high-mountain ecosystems are extremely important and deserve much more of our research attention.

Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from Ron Lanner)—Should not special efforts be made to preserve, in place, high-elevation forests, as a research resource? Is the Forest Service going to do so?

A.—I certainly agree that high-elevation sites should be made available as a research resource. Currently the Forest Service is in the process of identifying different forest types or areas with unique features to be set aside as Research Natural Areas (RNA's). A number have already been designated and surely some of them will be high-mountain ecosystems. If you desire to know the location of specific RNA's or to conduct research on them you should contact the responsible Station Director or Regional Forester.

Q. (from Anonymous)—Will the Forest Service really give sustained support to high-mountain resources research?

A.—As I noted in my presentation there is strong competition for research funding. While we may have the desire to sustain long-term research programs in such areas as the high-mountain forests, we constantly have to re-evaluate our priorities. Therefore, it is very important that the public has a high awareness of the importance of such research. This is where you can help. Anytime you have an opportunity to address the importance of research in high-mountain forests in public gatherings or brief Congressional delegations, you should do so.

Q. (from Diana Tomback)—In view of the fragility of the high-mountain ecosystems, do you foresee any policy protecting these ecosystems from any commercial impact in National Forest and wilderness areas in the near future?

A.—There will certainly be increasing pressure for commercial development in high-mountain resources. We are already seeing increased requests for development of winter recreation. Officially designated Wildernesses are, of course, already protected from further development; however, nonwilderness areas in National Forests are available for multiple use. Good research is the key element in establishing sound future policy on use of these areas. The better we understand the high-mountain ecosystems, the better we will be able to manage development.

SESSION 2

High-Mountain Resources of North America

Richard Kracht
Session Coordinator

The United States and Canada have much in common with the geology and biology in the high mountains of the West that span the borders of these two countries—both can benefit from the knowledge gained on either side of the border. This session aimed at describing what resources result from this commonly shared environment and how resources are viewed under different public land management objectives.

LATE QUATERNARY HISTORY OF WHITEBARK PINE IN THE ROCKY MOUNTAINS

Richard G. Baker

ABSTRACT

The fossil record of whitebark pine (Pinus albicaulis) *is still sketchy. Only two fossil sites older than the last glacial advance contain whitebark pine pollen and macrofossils, but they show that it was present in the Yellowstone National Park region for over 100,000 years. The history of whitebark pine during the last 15,000 years in parts of the Rocky Mountains is fairly well understood.* Pinus albicaulis *apparently survived the last glaciation in protected areas throughout much of the Northern Rocky Mountains. It was well adapted to colonizing the treeless sites with mineral soils that prevailed during late-glacial times (about 15,000 to 10,000 years ago). Whitebark pine remained abundant, probably as a subalpine forest species, in many areas at the beginning of the early Holocene (about 10,000 to 8,000 years ago). During "Altithermal" warming in the middle Holocene of the Rocky Mountains (about 8,000 to 4,000 years ago), the species apparently was confined to high-altitude sites, and it has not substantially recovered during the slightly cooler climates of the late Holocene (the last 4,000 years).*

INTRODUCTION

To understand the ecology and distribution pattern of any plant species, it is useful, if not essential, to know its history through the study of fossil remains. When extensive fossil records became available for many species in both the eastern and southwestern United States, new concepts of community evolution and biogeography were mandated (Davis 1983; Spaulding and others 1983; Thompson 1988; Watts 1983; Webb 1988). Unfortunately, the fossil record is incomplete; for most species and most regions, such information is not available. The fossil record for whitebark pine (*Pinus albicaulis*) in the northwestern United States and Canada has been investigated during the past two decades, and the resulting paleoecological and paleogeographical information may help in understanding its present status. The purpose of this paper is to outline the evidence of the Late Quaternary occurrence of whitebark pine as it is known from the fossil record. The longest records and strongest evidence come from Yellowstone National Park and surrounding areas near the southeastern margin of its range, and these sequences will be emphasized. Other records from northern Montana, Idaho, Washington, and Alberta, Canada, will also be discussed.

The past distribution of whitebark pine can be inferred from (1) the present distribution, (2) the occurrence of high percentages of haploxylon pine pollen, (3) high PAR (pollen accumulation rate) values of haploxylon pine pollen (measured in grains per square centimeter per year), and (4) the occurrence of needles or other macrofossils of pine.

Using present distribution of whitebark pine or any other species to infer past ranges is the most speculative approach. It has often been suggested, for example, that the disjunct occurrence of trees like eastern white pine (*Pinus strobus*) and larch (*Larix laricina*) in the Midwest was a relict of the last (Wisconsinan) glacial episode; fossil evidence indicates that they are late Holocene immigrants (Davis 1979; Webb 1988).

Pollen percentages are a more useful though still imperfect method of studying past pine distribution. There are numerous pollen sequences in some areas of the Rocky Mountain region. The problem is in identifying pine pollen to species (Hansen and Cushing 1973). Two studies that deal with identification of conifer pollen do differentiate species of pine in the Northern Rocky Mountains (Bagnell 1975; Weir and Thurston 1977), using the scanning electron microscope. Virtually all routine pollen analysis, however, is done with a light microscope, and thus few palynologists use the criteria of Bagnell (1975) and Weir and Thurston (1977) in identifying pine to species. In fossil pollen studies, identifications are generally only to the subgeneric level, and many are only to the genus level.

Few pine species presently grow in the Northern Rocky Mountains, and the assumption is often made that only these species have been present during late Quaternary time. Support for this argument comes from the American Southwest, where there is strong evidence that several pine species moved vertically up and down mountain slopes and did not show major geographic shifts during this period (Thompson 1988). In the Northern Rocky Mountains, macrofossil studies suggest that the same type of movement occurred at least during the last

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15,000 years. *Pinus albicaulis* and limber pine (*P. flexilis*) are the only haploxylon pines in most of the Rocky Mountain region, though western whitepine (*P. monticola*) is present in northern Idaho and Montana. The co-occurrence of haploxylon-type pine pollen with *Picea* and *Abies* may help to distinguish *P. albicaulis* from *P. flexilis* and *P. monticola*, which have different associations in this region today. Studies of the modern pollen rain in Yellowstone and Grand Teton National Parks indicate that haploxylon/diploxylon pine pollen ratios are highest at high elevations at or near treeline, and are associated with peaks in spruce (*Picea*) and fir (*Abies*) pollen. Ratios are lowest in lodgepole pine (*Pinus contorta*) forests, and are intermediate and associated with Douglas-fir (*Pseudotsuga*) pollen at lower treeline, where *P. flexilis* occurs (Baker 1976; Barnosky 1987).

PAR values are more precise in determining the local presence of a taxon. PAR values reflect the actual deposition rate of pollen through time. Generally, these values are very low or zero when a taxon is absent, and they jump rapidly to high values when the taxon arrives at a site. Calculation of PAR requires an accurate chronology established by radiocarbon dating or varve record to provide the deposition rate, and few studies in the Rocky Mountains have used this method.

Studies of plant macrofossils are also not common, but where available, they establish more firmly the local presence of the tree. Fossil needles of *P. albicaulis* can be determined on the basis of morphology: they have both dorsal and ventral stomata, distinguishing them from *P. monticola*, and strongly thickened endodermal cells compared with *P. flexilis*. Even if this latter distinction cannot be made (perhaps because of poor preservation), the association of whitebark/limber pine needles with those of subalpine fir (*Abies lasiocarpa*) and Engelmann spruce (*Picea engelmannii*) in the Central and Northern Rocky Mountains would suggest that whitebark pine was present on ecological grounds. In this region limber pine is associated with the lower treeline and whitebark pine with the upper treeline. A cautionary note is needed, however, because in the Southern Rocky Mountains, where whitebark pine is absent, limber pine grows at the upper treeline.

The modern distribution of *P. albicaulis* is likely controlled by a number of factors, of which climate is probably most important. Arno and Hoff (1989) have summarized climatic factors that characterize modern *P. albicaulis* stands. The general distribution follows boundaries of airmasses that determine when precipitation occurs (Mitchell 1976). Whitebark pine grows in areas of mainly high winter precipitation and dry summers in interior locations, and of both summer and winter precipitation in the Sierra and Cascade Ranges.

The Quaternary climatic history of the Yellowstone National Park region has been summarized by Porter and others (1983) and Richmond (1986a, 1986b). The region has a long and complex history of glaciations and interglaciations extending back to over 2 million years. Since the last (Sangamonian) interglaciation ended about 120,000 yr B.P., the Wisconsinan Glaciation (about 120,000-10,000 yrs B.P.) occurred, but glaciers were not extensive during that entire interval. Part of that period was dominated by nonglacial climatic episodes that ranged from warm to cold, based on both physical and biological evidence (Baker 1986; Richmond 1986a). As the last Wisconsinan glaciers retreated, a period of cool climate persisted prior to postglacial warming; this interval is herein called the "late-glacial" (15,000-10,000 yrs B.P.). The Holocene follows the late-glacial, and is used in this paper to mean the relatively warmer period during the last 10,000 years, with the exact timing of the warming depending on geographic position and altitude.

YELLOWSTONE NATIONAL PARK REGION

Although *Pinus albicaulis* probably arose from ancestral stock (in the Subgenus Strobus, Section Strobus, Subsection Cembrae) tens of millions of years ago during the Tertiary Period (Axelrod 1986), apparently no fossils referable to that stock are known in North America. In fact, I do not know of any published fossil records of whitebark pine older than Late Quaternary.

Earliest Records

Several unpublished pollen sequences have been completed from Early to Late Pleistocene sediments by E. B. Leopold, J. P. Bradbury, and W. Mullenders (Richmond 1978). Although no separation of pine pollen is made in these reports, association with spruce and fir would suggest that whitebark pine may have been present.

The earliest published records known from the Quaternary date back only to the waning stages of the previous (Illinoian) glacial period, approximately 140,000 yr B.P. The lowest exposed levels of a deltaic section along Beaverdam Creek in the southeastern part of Yellowstone National Park (fig. 1) contain pollen of spruce, fir, and haploxylon pine along with that of juniper, sagebrush, grass, and sedge (Baker 1981). This pollen assemblage strongly resembles much younger late-glacial assemblages in the Yellowstone Park region, and indicates a cold, near-treeline environment. No macrofossils were recovered from this section, but it is likely that the pine is whitebark pine.

Somewhat higher in the same deltaic sequence, overlying a very warm-climate pollen sequence, haploxylon pine pollen and needles are associated with pollen and macrofossils of spruce, fir, Douglas-fir, poplar, and dwarf birch (Baker 1986). This assemblage is much more heterogeneous, and the pine could be either whitebark or limber pine. Poor needle preservation precluded sectioning to determine which species was represented.

Another climatic fluctuation began an estimated 80,000 yr B.P. (Richmond 1986a) and is recorded by the sequence at Grassy Lake Reservoir, near the southwest corner of Yellowstone National Park (Baker 1986) (fig. 1). Pollen percentages of total pine are low (<30 percent) at

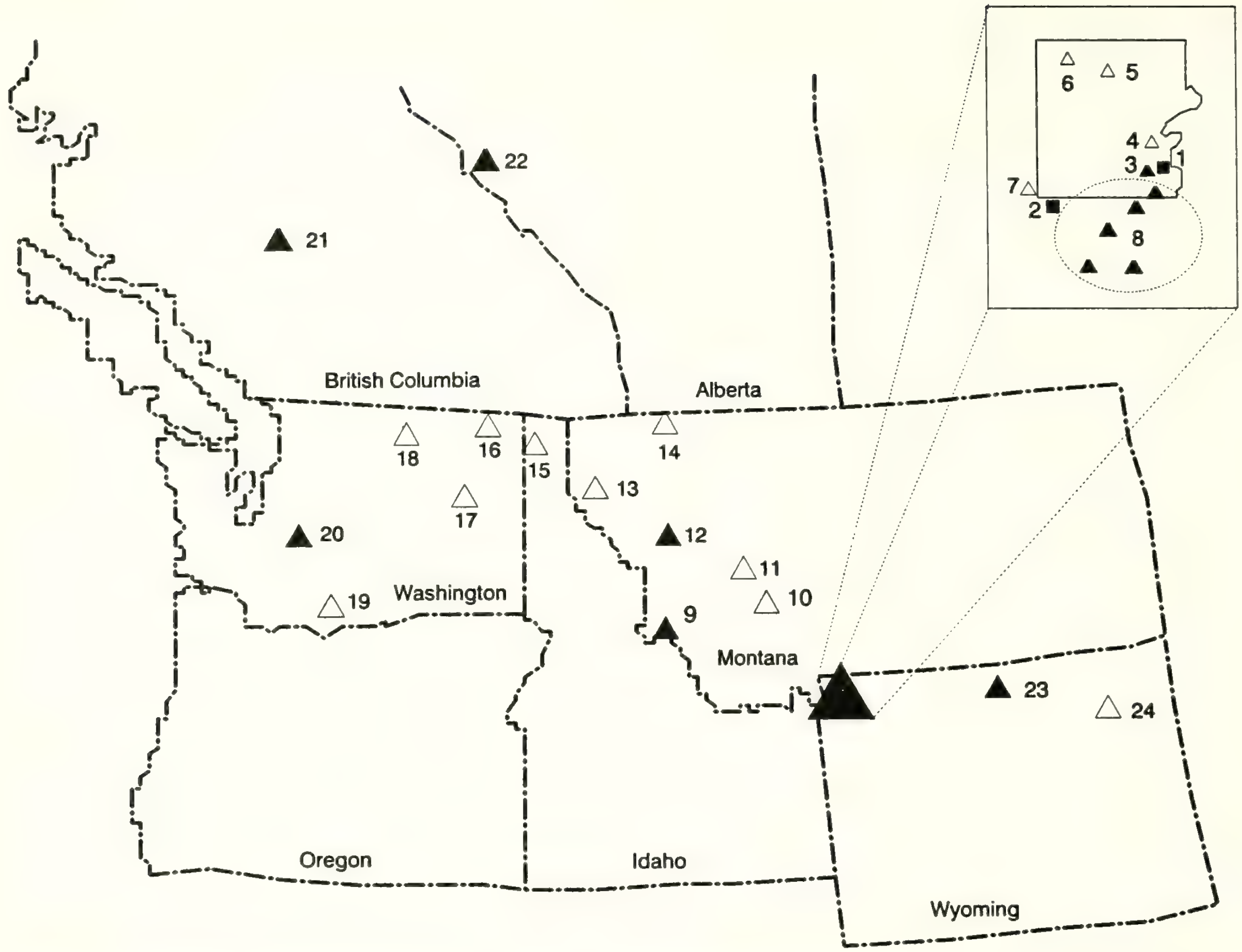

Figure 1—Location of sites considered in this paper. Squares (in the Yellowstone area inset) = sites older than 50,000 years B.P.; triangles = sites younger than 20,000 years B.P.; open markers indicate that pollen only was studied; filled markers indicate that both pollen and macrofossils were studied. 1-Beaverdam Creek (Baker 1981, 1986; Baker and Richmond 1978); 2-Grassy Lakes Reservoir (Baker 1986); 3-Buckbean Fen (Baker 1970, 1976); 4-Cub Creek Pond (Waddington and Wright 1974); 5-Blacktail Pond (Gennett and Baker 1986); 6-Gardiner's Hole (Baker 1983); 7-Cub Lake (Baker 1983); 8-group of five sites studied by Barnosky (1987); 9-Lost Trail Pass Bog (Mehringer and others 1977); 10-Forest Lake site (Brant 1980); 11-Telegraph Creek site (Brant 1980); 12-Sheep Mountain Bog (Mehringer 1985); 13-Teepee Lake (Mack and others 1983); 14-Guardipee Lake (Barnosky 1989); 15-Hager Pond (Mack and others 1978b); 16-Big Meadow (Mack and others 1978a); 17-Waits Lake (Mack and others 1978c); 18-Bonaparte Meadows (Mack and others 1979); 19-Carp Lake (Barnosky 1984, 1985); 20-Davis Lake (Barnosky 1981); 21-Castle Peak site (Clague and Mathewes 1989); 22-Wilcox Pass site (Beaudoin and King 1989); Watchtower and Excelsior sites (Luckman and Kearney 1986); Lake O'Hara (Reasoner and Hickman in press); 23-Sherd Lake (Baker 1983; Burkart 1976); 24-Antelope Playa (Margraf and Lennon 1986).

the base, indicating that pine trees were scarce to absent at the site, but the percentages are strongly dominated by haploxylon pine pollen. Spruce, sagebrush, grass, and sedge pollen are dominant. In the overlying zone, spruce pollen percentages and macrofossils rise first, followed shortly by those of whitebark pine type and fir, and last by those of lodgepole pine. This sequence also is similar to late-glacial sequences and indicates vegetational change from tundra to open parkland and finally to forest. Apparently spruce was the first migrant in the area, with whitebark pine following shortly after.

A second, stratigraphically younger sequence along Beaverdam Creek (fig. 1) extends from 70,000 yr B.P. to possibly 50,000 yr B.P. This thick section of laminated lake sediments records cold tundra conditions for nearly the entire period represented. An apparently short-lived interval near the base has peaks in haploxylon pine, spruce, and fir pollen (Baker and Richmond 1978). The same interval at a nearby section contained needles of spruce and whitebark pine (Baker 1978). Apparently trees were scarce during this long, cold period, but they were near enough to colonize local habitats during this earlier, slightly warmer interval.

The interval from about 50,000 to 15,000 yr B.P. is very poorly known. No known sequences in Yellowstone National Park contain sediments of this age, and during much of that time the Park was almost completely covered by a Late Wisconsinan ice cap (Pierce 1979; Porter and others 1983). Elsewhere, few long records from unglaciated areas in the Rocky Mountains and Pacific Northwest are available. Sites in western, west-central, and southern Washington date back more than 20,000 yr B.P. and record very cold conditions. There, however, the first pine to colonize was lodgepole, not whitebark, pine (Barnosky and others 1987; Heusser 1983, 1985). Another sequence that extends back more than 20,000 yr B.P. is from the Chuska Mountains of New Mexico (Wright and others 1973), well beyond the present range of whitebark pine. Some of the most reliable identification of pollen from several species of pine was performed there (Hansen and Cushing 1973), and no evidence of whitebark pine was found.

A different type of record provides paleoecological information from full-glacial and late-glacial time from the American Southwest (Spaulding and others 1983; Van Devender and others 1987). Packrats build nests and middens of local plant materials, which accurately represent the surrounding vegetation. Preservation of plant macrofossils in ancient nests is superb, and they have been used extensively in the arid mountains and deserts to provide key information on the distribution of many plant species, including several pines. Unfortunately, whitebark pine has not been recorded in these middens.

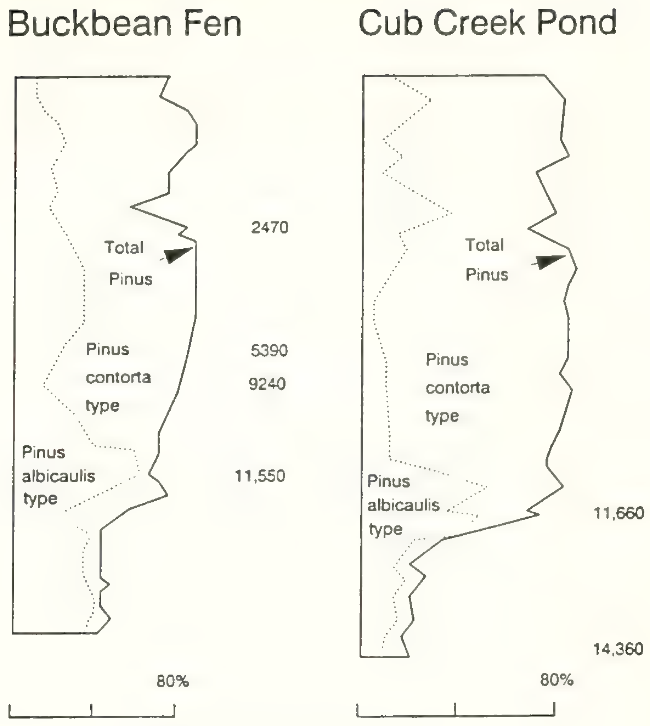

Figure 2—Total pine and whitebark pine-type pollen percentages from Buckbean Fen and Cub Creek Pond, Yellowstone National Park. Modified from Baker 1976 and Waddington and Wright 1974.

Late-Glacial and Holocene Records

Several sites in and near Yellowstone National Park contain late-glacial (about 15,000 to 10,000 yr B.P.) and early Holocene (about 10,000 to 8,000 yr B.P.) remains of whitebark pine. The record at Buckbean Fen (fig. 1) (elevation 2,380 m) is typical (Baker 1970, 1976). Prior to about 12,000 years ago sagebrush (*Artemisia*) and other shrubs and herbs dominated the pollen sequence. Pollen percentages of *Pinus* were low, but the dominant type was haploxylon, probably *P. albicaulis* (fig. 2). Macrofossils indicate that common juniper, (*Juniperus communis*), dwarf birch (*Betula glandulosa*), and open-ground subalpine and alpine herbs were present. Together these data indicate that an open landscape of tundralike vegetation prevailed. Engelmann spruce and whitebark pine may have been present in locally favorable microhabitats. Engelmann spruce, whitebark pine, and poplar (probably balsam poplar) were the first trees to migrate onto raw mineral soils of the deglaciated area. As the climate became warmer about 11,500 years ago, the pollen and macrofossil record indicates that *P. contorta* immigrated into the area, and a mixed forest of *P. albicaulis* and *P. contorta* covered the region. By about 10,000 yr B.P. pine dominance in the pollen and macrofossil record shifted from *P. albicaulis* to *P. contorta*, indicating that whitebark pine was gradually phased out, and *P. contorta* forests became dominant as they are today. During the late-Holocene, even though *Picea* and *Abies* pollen and macrofossils became more abundant, *P. albicaulis* did not return to this site (Baker 1970, 1976).

The other sites in Yellowstone National Park (fig. 1) show similar pollen sequences. These sites include Cub Creek Pond (elevation 2,485 m) (Waddington and Wright 1974), Gardiners Hole (elevation 2,215 m) (Baker 1983), Blacktail Pond (elevation 2,018 m) (Gennett and Baker 1986), and Cub Lake (elevation 1,840 m) (Baker 1983). The late-glacial pollen spectra at all these sites are similar to that at Buckbean Fen, with high percentages of nonarboreal pollen, and maxima of spruce and fir percentages and of whitebark-pine-type/lodgepole-pine-type pollen ratios. Although macrofossils are not available for these sites, the pollen sequences indicate comparable late-glacial paleoenvironments, even at low elevations.

The late-glacial to Holocene transition at 10,000 yr B.P. also is similar, with a rapid rise in total pine, mostly haploxylon, followed by a period of whitebark pine and lodgepole pine dominance. *Pinus contorta* is dominant during the middle and late Holocene, though *P. albicaulis* pollen rises slightly in the late Holocene at Cub Creek Pond (fig. 2), the highest elevation site sampled in the Park. Presumably *P. albicaulis* was confined to timberline sites during the middle Holocene, and remained at relatively high elevations during the late Holocene.

Barnosky (1989a) has studied several sites ranging in elevation from 2,073 m to 2,634 m between the southern boundary of Yellowstone National Park and Jackson Hole, WY (fig. 1). She has used pollen percentages and pollen accumulation rates, as well as macrofossils, to establish patterns of colonization after deglaciation. Her work indicates that a period of treeless vegetation followed deglaciation, as in Yellowstone National Park. Subsequently, *P. engelmannii* arrived at most sites, followed shortly by *P. albicaulis* and *A. lasiocarpa*. In early Holocene time *P. contorta* and *Pseudotsuga menziesii* forests prevailed, and low levels of haploxylon pine pollen suggest that whitebark pine was confined to exposed sites at high elevations.

Pinus albicaulis is not present today in the Bighorn Mountains in eastern Wyoming (figs. 1 and 3), and pollen analysis from three sites there suggests that it never grew there during the last 13,000 years (Baker 1983; Burkart 1976). It also never occupied the Wyoming basins during late-glacial times; at least the Powder River Basin (figs. 1 and 3) was apparently covered by late-glacial steppe (Markgraf and Lennon 1986). There is an excellent record of whitebark pine in the Bitterroot Mountains (fig. 1) to the west of Yellowstone National Park (Bright n.d.; Mehringer and others 1977). Both *P. albicaulis* and *P. engelmannii* pollen and needles appear about 11,500 yr B.P. at Lost Trail Pass Bog (elevation 2,152 m) and were codominants with *P. contorta* and *A. lasiocarpa* during the early Holocene. After a mid-Holocene warm period about 8,000 to 4,000 yr B.P., when an open forest of *Pseudotsuga* was apparently present, closed forests of *P. albicaulis*, *P. contorta*, *A. lasiocarpa*, and *P. engelmannii* returned to the site and remain to the present time.

NORTHERN ROCKY MOUNTAINS AND ADJACENT AREAS

Brant (1980) found pine pollen curves similar to those in Yellowstone National Park at two sites in west-central Montana (fig. 1). Haploxylon/diploxylon pine pollen ratios were highest during the late-glacial period, when total pine percentages were relatively low, and both haploxylon and diploxylon pines were present during the early Holocene (fig. 3). Whitebark pine apparently was not abundant during the late Holocene, although it is still present

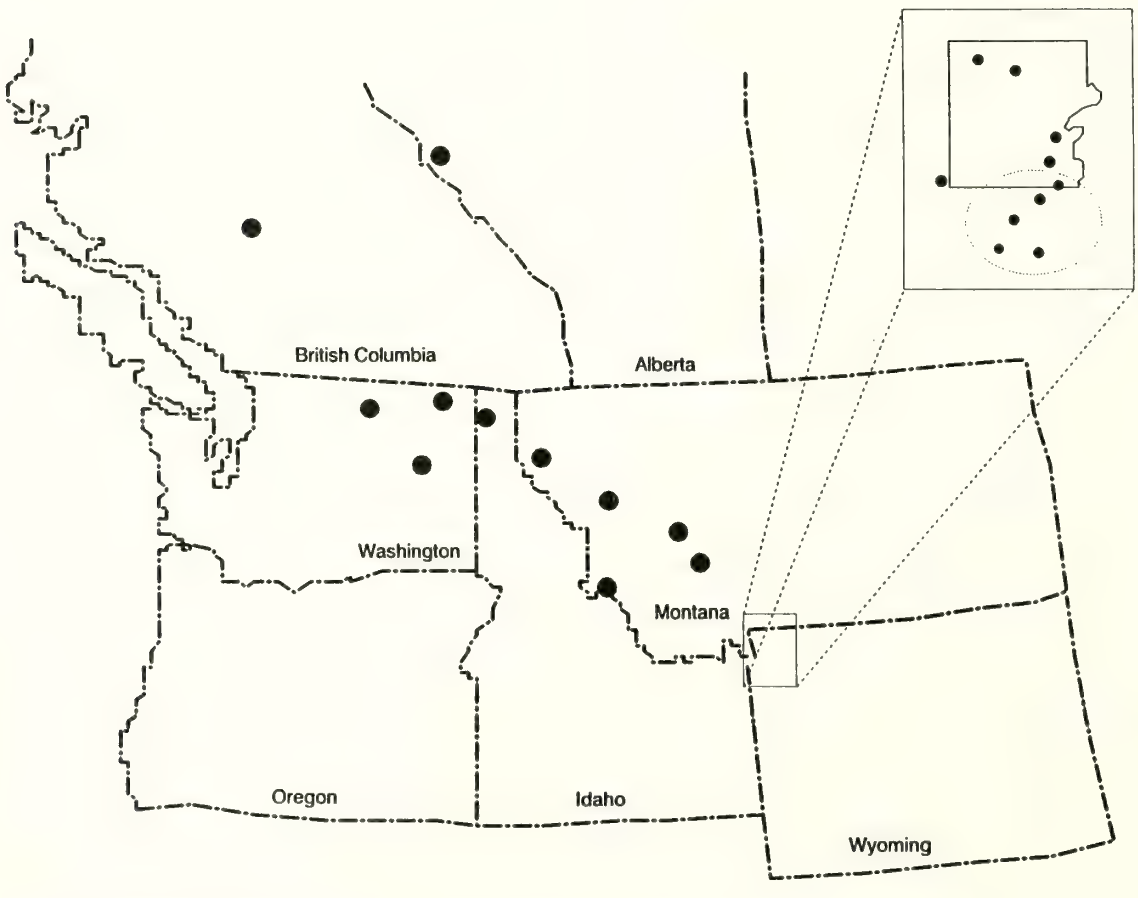

Figure 3—Sites where *Pinus albicaulis* was present between15,000 and 8,000 years B.P.

there. A very similar sequence occurs farther northwest at Sheep Mountain Bog (elevation 1,920 m) in northwest-central Montana (Mehringer 1985), where the high ratios of haploxylon/diploxylon last until about 9,500 yr B.P. Needles of whitebark pine confirm the tree's presence in this lower elevation site (Mehringer 1989). At this site, as at Lost Trail Pass Bog, haploxylon pine pollen remains at moderate levels throughout the Holocene. Both *P. flexilis* and *P. albicaulis* occur in the area at present; in the middle and late Holocene, limber pine may also have contributed to the haploxylon pine pollen rain.

Apparently the Great Plains adjacent to the Northern Rocky Mountains were not tree covered in late-glacial time, despite the lowering of treelines and forest zones (figs. 1 and 3). Pine pollen percentages are predominantly diploxylon and suggest that lodgepole pine was important in the nearby mountains, but that the trees were not present at Guardipee Lake east of Glacier National Park during the last 12,000 years (Barnosky 1989b).

A number of sites between the Northern Rocky Mountains and the Cascade Range provide pollen, but not macrofossil evidence for the past distribution of whitebark pine (see summaries in Baker 1983; Barnosky and others 1987; Heusser 1983, 1985; Mehringer 1985). *Pinus monticola*, *P. flexilis*, and *P. albicaulis* are all present today in the Northern Rocky Mountains, so the identification of *P. albicaulis* on pollen morphology alone is less certain in these studies. Nevertheless, it is the most likely contributor of haploxylon pine pollen in the late-glacial and early Holocene, based on other conifers present at that time.

Several sites in northwestern Montana and northern Idaho (fig. 1) show that both haploxylon and diploxylon pine pollen were part of the late-glacial pollen flora (fig. 3), along with *Picea* and *Abies* (Mack and others 1978a, 1978b, 1978c, 1979, 1983). The haploxylon pine pollen probably represents mostly whitebark pine, although some *P. monticola* pollen has been found according to Mack and others (1978b). The diploxylon pine pollen is thought to represent *P. contorta*, as opposed to *P. ponderosa*, which also grows there today. These conifers were apparently present in an open parkland, judging by the large amount of nonarboreal pollen in the late-glacial.

From the west side of the continental divide to the east flank of the Cascade Range in Washington (fig. 1), a number of sites indicate that a steppelike environment with scattered pine was present in the late-glacial and early Holocene (Barnosky and others 1987; Mehringer 1985). At the west end of this transect the pine pollen is mostly diploxylon. Apparently whitebark pine was rare or absent along the base and eastern slope of the Cascade Range. However, a recent report on fossil logs at timberline in southern British Columbia (figs. 1 and 3) indicates that *P. albicaulis* grew in the southern Canadian Cordillera 9,000 years ago (Clague and Mathewes 1989). In fact, timberline was 60 to 130 m higher at that time in the Pacific Northwest. Few, if any, pollen studies in the Cascades indicate that whitebark pine was present there. Whitebark pine was not present in a very careful study of plant macrofossils from the flanks of Mt. Rainier, for example (Dunwiddie 1986). Further careful work on the source of the pine pollen in that area is needed. The presence of both haploxylon and diploxylon pine pollen in the northeastern Washington highlands suggests that mixed *P. albicaulis*-*P. contorta* parklands were present there shortly after deglaciation. It is likely that *P. albicaulis* has been present, if not abundant, ever since in that area.

Recent studies in the Canadian Rocky Mountains (fig. 1) also indicate the early Holocene presence of *P. albicaulis* (fig. 3) (Beaudoin and King 1989; Kearney and Luckman 1983; Luckman and Kearney 1986; Luckman and others 1984; Reasoner and Hickman in press). It is the only high-altitude haploxylon pine in the region, and all sites investigated are in alpine meadows near the upper treeline. Both pollen and macrofossils (needles) of *P. albicaulis* were present shortly after deglaciation. Apparently whitebark pine survived glaciation locally and was able to colonize new sites effectively. It was relatively abundant during the early Holocene, became less common during the warmer middle Holocene, and again increased in abundance in the late Holocene.

DISCUSSION

From the fossil evidence, it seems clear that *P. albicaulis* was an important early invader on deglaciated ground throughout the Central and Northern Rocky Mountains. Its present ecology is well suited to such an environment. Arno and Hoff (1989) described its present treeline position, where it is well adapted to mineral soils and open, sunny habitats. These conditions must have been prevalent over large areas during late-glacial time.

The fossil records show that whitebark pine established much of its modern range by at least 10,000 yr B.P. (fig. 3). It seems likely that the tree survived glaciation in protected habitats in most areas. Present distribution of whitebark pine is heavily dependent on Clark's nutcrackers, which are almost solely responsible for dispersal of the tree (Hutchings and Lanner 1982; Tomback 1978). These birds collect, transport, and bury its seeds in caches. The common occurrence of many boles of whitebark pine is ample evidence of the effectiveness of these birds as agents of dispersal. It is likely that Clark's nutcrackers coevolved with the pines long before the last glaciation, and thus they would have been effective in the rapid dispersal of whitebark pine from sites where it survived full-glacial conditions. Similar relationships are present between fagaceous trees and blue jays in eastern North America, and blue jays have been cited as an important factor in the rapid dispersal of oaks in the early Holocene (Johnson and Webb in review).

During the early Holocene, whitebark pine apparently remained abundant in many areas, along with spruce, fir, and lodgepole pine. *P. albicaulis* probably occupied both of its present niches (climax at treeline and seral in spruce-fir-whitebark pine forests) (Arno 1986). Warm conditions during the middle Holocene may have been responsible for the apparent decline of whitebark pine. In a few places, pollen sites near treeline indicate that the tree became more abundant again during the late Holocene, but it never seems to have returned to its early Holocene prominence. If warmer climate was responsible

for middle Holocene decline, then global warming from the "greenhouse effect" could be very detrimental to the future of the whitebark pine ecosystem.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from Lawrence McHargue)—Does the recent history of whitebark pine in the Sierra Nevada parallel that in the Rocky Mountains?

A.—It is difficult to say for two reasons. One, there are many more species of pine today in the Sierras, and this causes greater uncertainty in the identification of pine pollen to species. Second, work in the Sierras is still in its infancy, and few detailed studies are available. People from the University of Arizona and from Northern Arizona University are working there, so we may soon have some answers.

Q. (from Anonymous)—Do you ever check: (a) current pollen catch with stand composition? and (b) differential degradation of pollen?

A.—(a) Several studies have related pollen rain to several different quantitative measures of stand composition, but these were mostly in the Eastern United States. We have done this qualitatively in Yellowstone, but quantitative stand data were not available. This is a very worthwhile project, and I hope that workers in the Rocky Mountains will soon be doing this. (b) Palynologists are very aware of differential degradation of pollen. Many taxa are simply never preserved, because their pollen wall is not resistant. For example, Juncaceae pollen is never found in the fossil record. Other pollen taxa have variable preservation. *Populus* is commonly cited here. It is often found where preservation is good, but it is one of the first pollen types to degrade under less-than-perfect conditions.

Q. (from Wendel Hann)—Why do you think whitebark pine has not spread into similar environments in Colorado?

A.—I really do not know. It may be climate, effective moisture, temperature, or possibly some combination may be limiting. Another possibility is that the distance between mountain ranges between Wyoming and Colorado is too great for Clark's nutcrackers to cover. It is a long way from the Wind River Range to the Snowy Range, or from the Wyoming Ranges to the Uinta Range. It is increasingly apparent, though, that many taxa in the Rocky Mountains did not move great distances horizontally during the last glaciation. Many moved up or down the mountain slopes. The reasons for this are also unclear.

Q. (from Mike Simpson)—How far can pollen travel to be deposited in one of your sections?

A.—Individual pollen grains can travel thousands of kilometers, but most of the pollen that accumulates in an area originates within a few tens of kilometers. In mountainous regions, several studies show that there is considerable vertical transport as well. Nevertheless, it is generally possible to recognize present-day communities from their modern pollen rain.

Q. (from Stephen Harvey)—How do you assume that *Artemisia* pollen is from shrubby species rather than subalpine species such as *A. michauxiana*?

A.—I do not assume that at all. I feel that both lowland and subalpine-alpine *Artemisia* pollen are represented, especially in late-glacial samples. Samples from modern tundra contain relatively high percentages of *Artemisia*, but not nearly as high as those from 15,000 to 10,000 years B.P. In both sets of samples, there are pollen types from such strictly lowland plants as greasewood (*Sarcobatus*), other chenopods, and Mormon tea (*Ephedra*) so it is likely that lowland *Artemisia* also is present. Modern pollen studies show that in many mountain ranges, strong winds blow pollen grains up from below. On the other hand, high-elevation species also are likely to be represented; they are close at hand, and pollen from other taxa of high-altitude plants is also present. I do not think that the source of *Artemisia* pollen is an either/or situation.

HIGH-MOUNTAIN RESOURCES ON NATIONAL FOREST LANDS

John W. Mumma

ABSTRACT

The high-mountain ecosystems are a component of National Forest lands that help make the National Forest System unique in its values. These ecosystems, characterized by whitebark pine, have a complex set of values. People have historically used these ecosystems for a range of commodity and noncommodity values. Common uses have included timber; livestock grazing; mining; camping; hiking; horseback riding; viewing wildlife, plants, and scenery; fishing; and hunting. Because of their unique environments, high-mountain ecosystems also have an important value in maintaining a diversity of plant and animal life. The value of these lands as watersheds and for producing water has not been recognized at the level deserved. Demands for all the products and values of these lands will increase. National Forest land managers and the public will need to use an integrated approach to develop, implement, and monitor management of these areas.

The value of whitebark pine as a food source for grizzly bears, and the complex relationship among grizzly bears, squirrels, and the Clark's nutcracker, is an example of the type of chain of effects that must be considered in management prescriptions. The potential loss of whitebark pine to blister rust is a problem that we must face and do our best to overcome.

INTRODUCTION

This paper will provide an overview of the high-mountain ecosystems of National Forest lands, a look at some of the important resources and values related to these ecosystems, and a discussion of key management issues.

LAND AREA

There are approximately 162 million acres of land in the National Forest System (USDA 1987). Of this, about 13 million acres are in high-mountain ecosystems, within the geographic range of whitebark pine (*Pinus albicaulis*). This is about 8 percent of the National Forest System. States that have National Forest high-mountain environments within the geographic range of whitebark pine include Washington, Oregon, California, Nevada, Idaho, Montana, and Wyoming (Arno and Hoff 1989). The total area of high-mountain ecosystems in National Forests, which includes high-elevation ecosystems outside the range of whitebark pine, would be considerably more.

The 13 million acres is a rough estimate. Inventory data for the National Forests is fairly limited in these environments, for several reasons. The primary reason is that these environments are usually not intensively managed and there has not been a demand in the past for refined inventory data. A second reason is that much of this land is unroaded and designated as wilderness or semiprimitive management areas. In addition, it is difficult to aggregate inventory data over such a large area.

In the future we will have better inventory data and a better geographic data base system to help store and summarize that information. The National Forest System is rapidly moving into the era of "information management." With systems such as stand exam (USDA, Forest Service, Northern Region, 1987) and ecodata (Hann and Jensen 1988) we can provide detailed vegetation and site data for different types of ecosystems. Our stand and soil survey map data bases linked to a geographic information system will provide us information at the geographic level that will serve for both small- and large-scale analysis. By the year 1991, the Northern Region plans to have a fairly complete data base for all lands. Most of the other Regions in the Forest Service have similar objectives.

DIVERSITY OF ECOSYSTEMS

Although there are roughly 13 million acres of high-elevation National Forest ecosystems within the geographic range of whitebark pine, only a small part of it is dominated by whitebark pine. The majority of this land is dominated by other high-elevation species. Other common subalpine tree species include subalpine fir (*Abies lasiocarpa*), lodgepole pine (*Pinus contorta*), spruce (*Picea engelmannii* and *Picea glauca*), mountain hemlock (*Tsuga mertensiana*), and alpine larch (*Larix lyallii*). Nonforest communities, dominated by a wide variety of herbaceous and shrub species, are also common in the subalpine and alpine zones. This wide range of flora and site conditions within these ecosystems provides for a wide diversity in plant and animal life.

A diversity of disturbance is also an integral component of the high-elevation ecosystems. Fire has played a dominant role in shaping the landscapes of the subalpine zone (Fischer and Bradley 1987; Fischer and Clayton 1983). In many of these ecosystems the interval between natural fires may be long, but the influence in shaping communities and in creating a variety of successional communities can be seen many years after a fire. Insects also play a

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key role along with fire. Although the mountain pine beetle kills mature lodgepole pine, it sets the stage for a stand-consuming fire. Natural regeneration of lodgepole pine is highly fire dependent, since it requires an ash or mineral seedbed and the cones often require heat treatment to release the seeds. Thus, the continuance of the lodgepole species depends on the disturbance factors that destroy the mature species.

The environment of high-elevation ecosystems itself causes continual disturbance to the vegetation. Freezing temperatures during any month of the year, wind damage, and snow damage can change communities and initiate successional change. Avalanche areas usually contain a distinct complex of communities that only occur due to the environment created from repeated disturbance.

In many areas of high-elevation ecosystems the communities are developing for the first time on substrate that is forming from primary succession after glacial retreat, flooding, erosion, or debris slides. Soils of these ecosystems are usually poorly developed and slopes are often steep. This great complexity of environments results in an equally large complexity of communities.

Animal communities in these ecosystems also often have complex relationships. Due to the severe environments, animals and plants have developed complex interrelationships that aid their ability to survive and reproduce. The interesting relationship among the Clark's nutcracker, squirrels, grizzly bears, and whitebark pine is a classic example of this type of intricate ecological relationship.

The diversity of the high-elevation ecosystems is exemplified by whitebark pine and the diversity of associated plants and sites where it occurs. Whitebark pine can be found as a common component with lodgepole pine on moist, lower elevation subalpine fir habitat types (Cooper and others 1987; Pfister and others 1977; Steele and others 1981). It is also found on high, subalpine ridgetops growing in open parklike stands associated with species such as mountain big sagebrush (*Artemisia tridentata vaseyana*) or Idaho fescue (*Festuca idahoensis*). At timberline, whitebark pine can be found with alpine species such as mountain heath (*Phyllodoce empetriformis*) and alpine willow (*Salix arctica*).

POSTSETTLEMENT USE AND IMPACTS

The great diversity of animal and plant communities and the rugged landscapes of the high-mountain ecosystems result in a wide variety of resources and values. During the early settlement of the late 1800's and the early 1900's, the primary resources that were valued by society were the potentials for mineral development and forage for domestic sheep. Since the mid-1900's, there has been a steady trend of society to emphasize a different set of values for these ecosystems. These values are more noncommodity in nature, such as hiking, camping, and viewing wildlife or scenic features.

During the period of extensive, and often heavy, sheep grazing in the West, which lasted from the middle 1800's to the early 1900's, many of these lands were severely impacted. At the same time, mining operations with associated widespread cutting of timber for mine shafts and lumber and poorly designed roads often led to severe impacts on the land and watersheds. Time, improved management, and rehabilitation have healed many of the problems resulting from these past impacts.

There has been a more subtle effect than that of mining or grazing on the high-mountain ecosystems, related to settlement by Europeans, that has caused a significant change in the resource values. This is the effect of fire suppression. In the ecosystems where natural fire frequencies were quite long, 50 to 70 years of fire suppression has not had a significant effect. In other ecosystems where the natural fire frequency is short to moderate, there has been a significant effect (Gruell 1983). The result of a departure from this natural fire frequency has been an increase in mature timber types, a shift of nonforest types to forest types, and a decrease in diversity of structural classes across the landscape. The resulting increase in fuels and fuel continuity can lead to significant problems when wildfires occur, as was evidenced by the 1988 fire season. The change in communities has also resulted in a reduction in habitat values for many animal species that depend on forage from early successional stages, such as elk and grizzly bears. A planned program of prescribed fire and fuels management should reestablish the natural balance.

An additional subtle impact of Europeans has been the introduction of exotic insects, diseases, plants, and animals. In the high-elevation ecosystems the introduction of blister rust, which attacks whitebark pine, and the introduction of exotic weeds have resulted in significant problems. Blister rust is causing a significant reduction of whitebark pine in many National Forests. This poses a challenge to managers and researchers to develop strategies to aid whitebark pine in regeneration and survival in the face of this exotic disease.

The introduction of exotic plant species by livestock, people, horses and mules, and other means is a significant problem and is causing a reduction in resource values. A good example of a plant species that historically has been introduced by domestic sheep to high-elevation lands is mountain knotweed (*Polygonom phytolacefolium*). Kentucky bluegrass (*Poa pratensis*) and dandelion (*Taraxacum officinale*) are two species that many people think of as being naturalized. In a sense they are, in that they have filled most of the niches that are available. However, the cost in loss of niches, and therefore diversity of native species, is significant. As time passes and other species, such as spotted knapweed (*Centaurea repens*) and leafy spurge (*Euphorbia esula*) fill their niches, they may also be accepted. The management of these species may well prove to be a much more difficult challenge to researchers and land managers than the fire management situation.

PRESENT USE AND IMPACTS

Mining, livestock grazing, and limited timber harvest are still important resource uses of high-mountain National Forest lands. However, the emphasis relative to the importance of the high-mountain resources, the types of resource use, and the impacts has changed significantly

within the last 30 years. At present, one of the most important uses of these lands is for recreation. Because of the diversity and rugged beauty of high-elevation lands, people find a lot of enjoyment in various activities in these areas. These activities include camping; hiking; horseback riding; picnicking; photography; viewing landscapes, plants, and animals; rock and mineral collecting; fishing; and hunting.

Along with the increase in recreational use, there have been associated impacts. Many of the high-elevation ecosystems are very fragile. People and their recreational stock or equipment can cause damage, just as mining and domestic sheep caused damage during the early days. This damage occurs at campsites, on trails, and along lakes, streams, and rivers. People also continue to aid the spread of exotic plants. Management of people and their recreational activities is a significant challenge that integrates sociology with resource management.

Of equal importance as recreation on the high-elevation lands is their value as watersheds. These lands provide catchment basins, sediment filters, and storage for water that is used at lower elevations during the summer. This water is critical in many areas for municipal use, irrigation, fisheries, industrial use, power development, and recreation.

The high-mountain lands of the National Forests play a key role in maintenance of biological diversity. The grizzly bear is probably one of the more well-known users of these ecosystems that is important to biological diversity. In drier areas, whitebark pine is a key food source for grizzly bears during the fall. The loss of whitebark pine due to the exotic blister rust disease not only is reducing the diversity of whitebark pine, but could hamper the grizzly bear recovery effort. Many other rare plants and animals are key components of diversity in these ecosystems. The common plants and animals and maintenance of their genetic diversity must be just as much a consideration for managers and researchers. At a larger scale, the diversity of communities or the landscape mosaic is an important resource, not only for wildlife and esthetics, but to provide ecosystem stability.

Air quality is a resource. It is a resource that is very difficult to manage because the pollutants that can degrade air quality can come from sources over which we have no control. The degradation of the ozone layer and the increase in CO_2, which could result in climatic change, are also effects that are difficult to manage. These are problems that we must deal with in large-scale cooperative efforts if we are to maintain environmental quality.

Wilderness, semiprimitive areas, and other natural areas are also a resource. These areas provide more than just recreation, watershed, and wildlife values. They provide a land system that is very important from other aspects. Because the management philosophy is to maintain natural systems, these areas provide excellent baselines for understanding ecological functions and values and can be used to evaluate effects of human activities on lands managed for products. They are also a reservoir for biotic diversity and provide a natural laboratory for scientific investigation of the natural world. Of most importance may be their value as an outdoor classroom for people young and old to learn about the natural world and how they fit in that world.

MANAGEMENT OF HIGH-MOUNTAIN ECOSYSTEMS

The National Environmental Policy Act of 1969 and the National Forest Management Act of 1976 have significantly changed the way National Forest activities are analyzed and evaluated. Forest Plans have been or are being completed for all the National Forests. These plans specify how the Forests will be managed for a 10-year period and set general direction for long-term management. The plans are developed with strong public involvement looking at a broad range of alternatives. Once the plan is complete the process of implementation begins, which takes a closer look at how and where projects will be carried out with continued public involvement.

Based on these plans, much of the lands that are high-elevation ecosystems will be managed as wilderness, semiprimitive recreation and wildlife areas, and developed recreation areas. Some of these lands are being managed for production of livestock, minerals, and timber values. However, projects are analyzed and planned using an integrated approach that assures that ecosystem quality is maintained or enhanced. In many cases road construction, timber management, and livestock grazing are used to improve access or vegetation composition for recreation, wildlife, and watershed purposes. Fire management plans are developed for each Forest and for specific wildernesses. These plans are designed to use fire as a tool to maintain the natural mosaic of communities and fuels.

The key to good management in these ecosystems is to have biologically and socially sound objectives supported by a thorough analysis. This analysis must be supported by a good inventory of the site, vegetation, and animal characteristics. The team members that conduct the analysis need to have a thorough understanding of the ecosystem relationships in reference to the types of site conditions, disturbances, and uses that are being planned. With this type of approach we can manage the National Forests to produce the desired values and maintain environmental quality.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from Anonymous)—In your talk you referred to integrated management of National Forest lands. With the functional emphasis on specific resources, such as timber or wildlife, do you feel the Forest Service can actually conduct management in an integrated manner?

A.—During the development of the Forest Service and even now, there has often been a heavy emphasis on specific resource functions. However, with the completion of Forest Plans, we have a commitment to implement management in an integrated manner. It is difficult to move a large organization through rapid change, but we plan to meet that challenge, and become a better-rounded integrated management organization.

HIGH-MOUNTAIN RESOURCES OF NATIONAL PARK SERVICE LANDS

Don G. Despain

Resources are usually thought of as those raw materials that are put through some manufacturing process to yield a product needed or useful to mankind. Such a definition cannot be applied to the high-mountain lands administered by the National Park Service. The management goal of the Park Service is to maintain ecosystems as uninfluenced by modern technology as possible. However, there are a number of "commodities" produced in the high country used by a number of species for maintenance and growth.

The high-elevation areas are summer ranges for large mammals. Temperatures are cool and grass is produced abundantly in the moist meadows at these elevations. Whitebark pine (*Pinus albicaulis*) produces a large, oil-rich seed important to squirrels, Clark's nutcrackers, and grizzly bears. The cool climate also attracts large numbers of backpackers and campers, and mountainous cliffs and peaks draw many mountain climbers.

On lands outside the Parks (and often adjacent to them) the management objectives call for exploitation of resources such as timber. Even in wilderness areas, practices such as livestock grazing and hunting are used to harvest some of the resources. One special contribution of the National Parks is providing a benchmark against which the effects of other, more-extractive management practices may be judged.

Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from Anonymous)—In order to ensure "naturalness" what measures is the NPS undertaking to reduce the impacts of high-intensity recreation that are characteristic of NPS lands?

A.—I can not presume to speak for the entire Park Service and am not too sure that I can speak for Yellowstone National Park. However, I can make a few personal observations. First, high intensity does not characterize all recreational use of NPS lands. Only 1 percent of Yellowstone is developed, and only the developed areas are sites of high-intensity recreation activity. The rest of the Park is backcountry, and even our backcountry use is largely limited to trails and designated campsites. I do not want to imply that this use does not affect the "naturalness" of the Park. It does. I guess it depends on whether you want to see the cup 95 percent full or 5 percent empty.

There are a number of regulations in force that limit what recreationists and others (including researchers) can do within the Park boundaries. Activities that alter the environment are generally discouraged. Where fishing pressure is high, catch-and-release fishing regulations are in place, and the fish populations are responding phenomenally well. Strict regulations regarding food storage at campsites have been instituted and enforced to keep bears from being unduly impacted by the visitors and vice versa. It appears now that the bears are returning to a more natural distribution. Overnight backcountry use is allowed by permit only, and the number of people at any one site is restricted. The number of climbers on popular climbing routes in other Parks is regulated to keep the natural environment as intact as possible. Some areas are intensively used. The frontcountry campgrounds are nearly full every night during the peak summer season. The developed areas are visited by enormous numbers of people. We do not operate under the pretense that places like Old Faithful and other developed areas are natural, but we try to keep the 99 percent that is not developed as "natural" as possible. For the most part, I think we are doing a pretty good job. Periodically we receive complaints that there are so many restrictions a person can not really enjoy camping and hiking in Yellowstone.

Q. (from Ron Hamilton)—Do you consider the management activities carried on in the adjacent National Forests surrounding Yellowstone an "experiment"?

A.—Yes! Our knowledge of this fragile, interconnected ecosystem—the environment, the organisms involved, and their relationships and interactions—is so rudimentary and fragmentary that I think we are a long way from managing it with any certainty of the outcome of our actions. Ecology is still a new science. We are still developing tools with which to look at our activities. The public furor over forest management practices is fueled to a certain extent by some ecologists and other scientists. That criticism is not entirely unjustified. This is not to say that the Forest Service is derelict. We have to manage according to the best available knowledge and political realities. I mean only to say that the best available knowledge is not sufficient enough to allow us to abandon the control areas or to assume that our management practices are anything but experiments. We still desperately need areas like the Park Service natural areas and others to act as benchmarks against which the results of our activities can be assessed. Until we can predict with a high degree of certainty the final outcome of our actions in all parts of the ecosystem we need to regard our management actions as experimental.

Summary of remarks presented at the Symposium on Whitebark Pine Ecosystems: Ecology and Management of a High-Mountain Resource, Bozeman, MT, March 29-31, 1989.

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DISTRIBUTION AND ECOLOGY OF WHITEBARK PINE IN WESTERN CANADA

R. T. Ogilvie

ABSTRACT

In the Provinces of British Columbia and Alberta, whitebark pine (Pinus albicaulis) *extends from latitude 49° to 55° N., through the Rocky Mountains, the Columbia Mountains, the Interior Plateau, the Cascade Mountains and the Coast Mountains. The species is usually restricted to the upper subalpine forest, occurring most abundantly at timberline, where it grows with Engelmann spruce* (Picea engelmannii) *and subalpine fir* (Abies lasiocarpa) *in the eastern mountains, and with mountain hemlock* (Tsuga mertensiana) *in the western ranges. It rarely forms stands with alpine larch* (Larix lyallii), *the other timberline tree in the southeastern ranges of these mountains. Whitebark pine occurs at 2,000 to 2,450 m above sea level in the eastern ranges, and 1,800 to 2,000 m in the western Coast and Cascade Mountains. Typical habitats are ridge crests and upper steep southwest-facing slopes with high wind-exposure and shallow snow. The growth form varies with altitude and habitat, ranging from tall, single-stemmed upright trees to dwarf single-stemmed bush krummholz and multistemmed krummholz. Limited age-class analyses show broad age-ranges and abundant young age-classes. The soils are shallow and rocky on colluvial and glacial till parent materials; their moisture regime varies from dry to mesic. Soil reaction varies from predominantly basic and calcareous to acidic. Regosols, Brunisols, and Podzols are the major soil profile types. In drier habitats, whitebark pine occurs in the* Juniperus communis, Arctostaphylos uva-ursi, *and* Shepherdia canadensis *vegetation-types; in the more mesic, snowier habitats it occurs in the* Vaccinium scoparium, Cassiope mertensiana, Phyllodoce glanduliflora, *and* P. empetriformis *vegetation-types.*

INTRODUCTION

Whitebark pine (*Pinus albicaulis* Engelm.) is one of the neglected coniferous species of western Canada. It has restricted distribution and sparse abundance; it is remote and difficult to access, and is of minor commercial importance. Although listed in botanical floras and tallied in forestry inventories, this species has received slight attention from botanists and foresters alike. Information on the distribution and ecology of whitebark pine in western Canada is scattered over a wide variety of sources: herbarium collections, field notes, graduate student theses, published and unpublished survey reports, and biophysical and resource inventories. Many of the sources deal with the subalpine forest as an entity, and the information on whitebark pine is peripheral. Where appropriate I have cited the source of information. Other sources of information on the species are in an Additional Readings section following the References section.

DISTRIBUTION

Figure 1 shows the distribution of whitebark pine in British Columbia and Alberta. This map is based on collections in the herbaria of the Royal British Columbia Museum, the University of British Columbia, the University of Victoria, and the Canadian Forestry Service, Victoria. Additional distributional data were provided by the Canadian Forestry Service from their records of fungal and insect collections on whitebark pine. These data were correlated with the map published by Krajina and others (1982).

In western Canada, whitebark pine is restricted to Alberta and British Columbia, extending from latitude 49° to 55° N. and from longitude 114° to 128° W. It is a species restricted to high mountains, occurring in several physiographic regions (Holland 1964). Whitebark pine is present in numerous ranges of the Coast Mountains, but primarily on their drier eastern slopes. In the Cascade Mountains it occurs in the Skagit Range, the Hozameen Range, and the Okanagan Range. On the Interior Plateau the species has scattered distribution on the isolated mountain peaks and ranges. This pine occurs extensively in the main ranges of the Columbia Mountains: the Monashee, Cariboo, Selkirk, and Purcell Ranges. The major occurrence of whitebark pine is in the Rocky Mountains on both sides of the Continental Divide, in the Border, Kootenay, Main, and Front Ranges.

The environmental diversity of these different mountains is considerable. The climate varies from the more maritime conditions of the Coast and Cascade Mountains to the dry continental climate of the Interior Plateau and the Rocky Mountains and the moister continental climate of the Columbia Mountains. In addition, the latitudinal differences are significant. The southernmost peaks of the eastern Cascade, Interior Plateau, Columbia, and Rocky Mountains have a pronounced summer-dry climate, with much of the growth water originating from snowmelt. In contrast, at the northern extremities of these mountains the climate is more boreal, with lower summer temperatures, and little or no moisture deficit.

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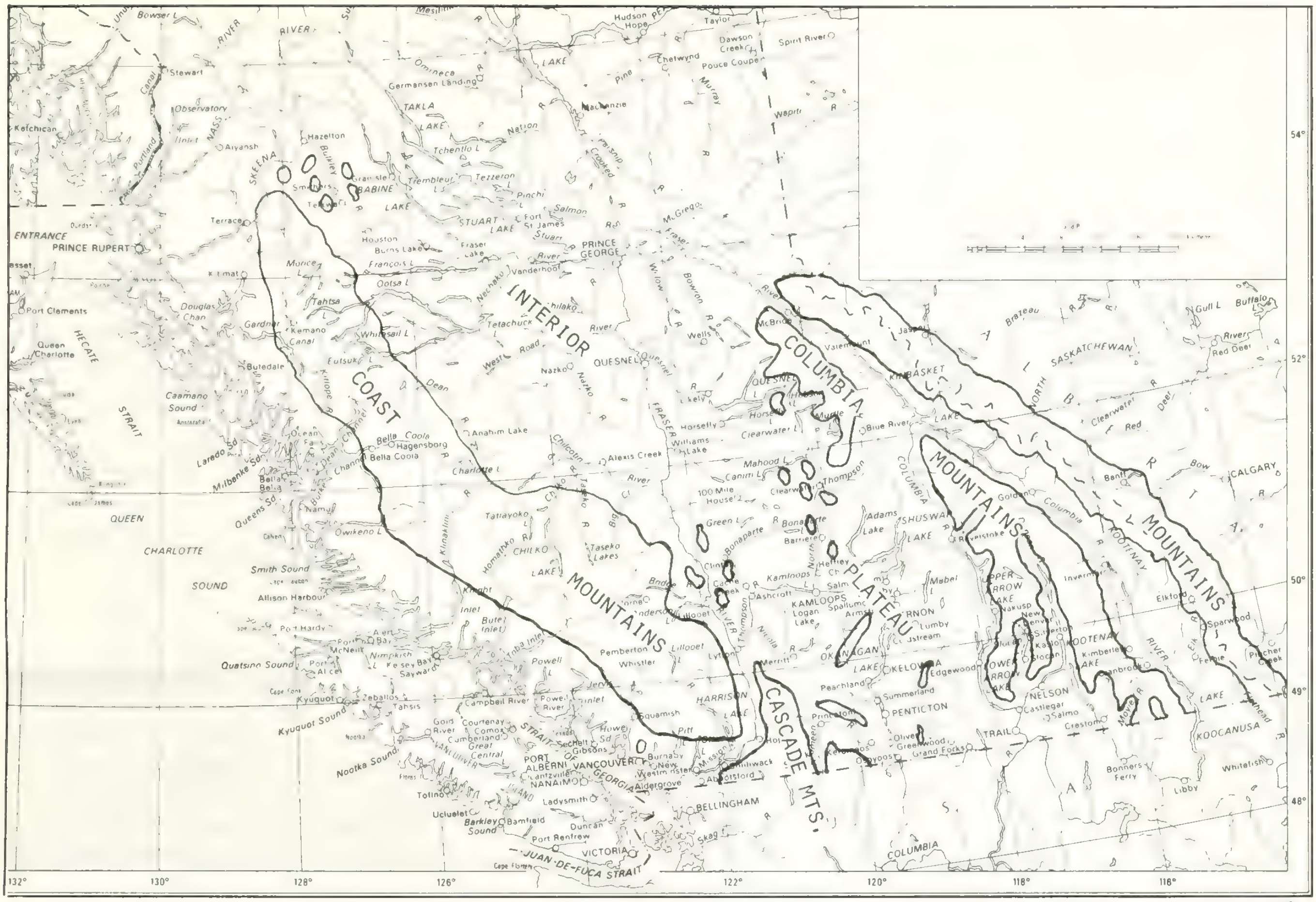

Figure 1—Whitebark pine (*Pinus albicaulis*) in western Canada.

ALTITUDINAL RANGE

Whitebark pine is typically an upper subalpine species, occurring most abundantly at timberline. It may grow as scattered trees as much as 700 m below timberline, and extend 300 m above timberline as small individuals less than 50 cm tall. On the west slope of the northern Rocky Mountains, valley bottom stands of whitebark pine occur at approximately 1,067 m elevation (Brayshaw 1989). On the lee side of the northern Coast Mountains, whitebark pine forms two altitudinal bands, one along the valley bottom at 900 m, and the other in the upper subalpine at 1,300 to 1,600 m (Pojar 1978; Yole and others 1989).

The upper altitudinal occurrence of whitebark pine krummholz is given in table 1 for the different mountain ranges of western Canada. These values for the altitudinal range of whitebark pine are consistent with the generalized geographic patterns of timberline: the species occurs at higher elevations in the southern mountain ranges and in the more continental and drier mountains.

Table 1—The upper altitude of whitebark pine in western Canada

Mountain range	Locale within range	Elevation limit
		Meters
Rocky Mountains	southern	2,300-2,400
	central	2,200
	northern	2,100
Columbia Mountains	Purcell Mountains	2,100-2,300
	Selkirk Mountains	2,000-2,200
	Monashee Mountains	2,200
	Cariboo Mountains	1,600
Interior Plateau	Okanagan Highlands	2,300
	Thompson Plateau	2,000-2,200
	Fraser Plateau	1,900-2,000
	Nechako Plateau	1,700
Cascade Mountains	Okanagan Range	2,200
	Hozameen Range	1,900-2,100
	Skagit Range	2,100-2,200
Coast Mountains	southern	2,000
	central	1,900
	northern	900 and 1,300-1,600

GROWTH FORM

The growth form of whitebark pine varies with altitude and habitat. In the more favorable habitats at lower elevations, the upright single-stemmed tree form occurs. Typically, these trees are short, attaining only 12- to 15-m heights. Exceptionally tall trees grow in southwestern Alberta and adjacent southeastern British Columbia at 1,676 m elevation, with trees 24 to 33 m tall and 51 to 79 cm diameter at breast height (Day 1967). Day reported that these trees were being logged and milled for pine lumber. The ages of these trees were over 250 years; other age measurements reported from Alberta are +300 years and 405 years (Baig 1972). This upright, single-stemmed tree form grows in mixed stands of hybrid spruce (*Picea engelmannii* x *Picea glauca*), subalpine fir (*Abies lasiocarpa*), and lodgepole pine (*Pinus contorta* var. *latifolia*). Stands of large, saw-timber-size whitebark pine also occur in the central Purcell Mountains at approximately 1,524 m elevation (Brayshaw 1989).

At higher elevations in the timberline zone, whitebark pine grows in a flat-topped candelabra form and a multistemmed form. Krummholz colonies of whitebark pine grow in the exposed, highest part of timberline. This form consists of a prostrate, multistemmed, low scrubby growth, with a few short upright flag stems (Baig 1972; Ogilvie 1978a). Signs of repeated injury and mortality of terminal branches from winter frost-drought (Tranquillini 1979) are indicative that the candelabra, multistemmed, and krummholz growth forms are environmentally induced, although a genetic basis comparable to mugo pine (*Pinus mugo*) in the European Alps has been speculated for these forms by Clausen (1963, 1965) and Crawford (1989).

LONGEVITY

Maximum ages of whitebark pine have been reported from dendrochronological studies of timberline trees in the central Rocky Mountains (Luckman and others 1984). In Mount Robson Park, BC, (lat. 52°42' N., long. 118°21' W.) 17 isolated whitebark pines at timberline (1,760 m) were aged by ring counts. Two trees had more than 450 annual rings, one snag had 520 rings, and the oldest tree had 713 rings, which when extrapolated to the center pith was an estimated 743 to 763 years. In Jasper Park, AB, (lat. 52°14' N., long. 117°14' W.) a single whitebark pine at upper treeline (approximately 2,200 m) had 550 annual rings. At the same locality, several dead standing snags of Engelmann spruce (*Picea engelmannii*), subalpine fir, and whitebark pine were dated by ^{14}C at between 900 to 1,160 yr BP (Jozsa 1989; Luckman and others 1984).

AGE COMPOSITION AND STAND DYNAMICS

Very few age analyses have been made of whitebark pine stands in western Canada. Day (1967) reported the results of a regeneration survey in two 5-acre mature stands of mixed spruce, subalpine fir, and lodgepole pine. Although there were only two parent trees of whitebark pine, the advanced regeneration (60 to 90 cm tall) of whitebark pine exceeded that of lodgepole pine, indicating that the former is a more successful competitor under closed stands with heavy shade and root competition.

Baig (1972) reported age analyses of six mature stands of mixed whitebark pine, Engelmann spruce, subalpine fir, and lodgepole pine in Alberta. All of the stands contained whitebark pine regeneration; two stands had subalpine fir regeneration, and only one stand had spruce regeneration. Whitebark pine had the largest number of individuals per stand, the broadest age range, and the oldest individuals. The dynamic trends of these stands indicate either pure whitebark pine stands, mixed whitebark pine and subalpine fir, or whitebark pine and spruce.

Many more age analyses are needed of stands from the different mountain systems to clarify the role of whitebark pine in relation to the other subalpine trees such as Engelmann spruce, subalpine fir, mountain hemlock (*Tsuga mertensiana*), and alpine larch (*Larix lyallii*).

GEOLOGY

The bedrock is highly variable in the different mountain systems in which whitebark pine occurs (Farley 1979; Holland 1964). In the Rocky Mountains, where whitebark pine has its major occurrence, the predominant rocks are sedimentary, consisting of limestones, sandstones, and shales. The Purcell Mountains consist of complex, folded limestones and quartzites with granitic intrusions. The Selkirk Mountains have complex, folded, erosion-resistant quartzites and limestones, gneiss, volcanics, and granitic intrusions. The Monashee Mountains are underlain by sedimentary and metamorphic gneissic rocks and volcanic intrusives. The Cariboo Mountains have folded and faulted, erosion-resistant quartzites and granitic rocks. Folded, intercalated volcanic and sedimentary rocks, and flat-lying lava flows, underlie the Interior Plateau. The Cascade Mountains are composed of folded and metamorphosed sedimentary and volcanic rocks with granitic intrusives. Batholithic intrusions of granites and gneisses predominate throughout the Coast Mountains.

SOILS

Soil parent materials derived from these rocks included bedrock debris at various stages of weathering, colluvium, and glacial tills. Very coarse fluvial and glacio-fluvial parent materials are reported by Pojar (1978) and Yole and others (1989) for valley bottom stands of whitebark pine in the northern Coast Mountains. The soil profile types are Lithic Regosols: (L-H), (Ah), *C*; Dystric and Eutric Brunisols: (L-H), *Ah*, *Bm*, C; and Orthic Humo-Ferric Podzols: *L-H*, Ae, *Bfh*, C (Canadian Society of Soil Science 1976; Canadian Soil Survey Committee 1978; Clayton and others 1977). The soil profiles are typically shallow, rocky, and coarse. Soil moisture conditions vary from dry to mesic. Whitebark pine in the Rocky Mountains is frequently associated with calcareous and basic soils, although some soil profiles are acidic.

Detailed soil profile descriptions and classifications are given in Achuff and others (1984a, 1984b), Coen and Holland (1976), Coen and Kuchar (1982), Coen and others (1977), Holland and Coen (1982), Lea (1984a), Sneddon and others (1972a, 1972b), van Ryswyk (1969), and Yole and others (1989). Discussions of problems in classifying and mapping subalpine and alpine soils are presented in Knapik (1978), Luttmerding and Shields (1978), and Valentine (1978).

General ecological descriptions of whitebark pine are given by Angove and Bancroft (1983), Krajina (1969), and Krajina and others (1982). According to these sources, whitebark pine occurs on xeric to mesic, nutrient-rich (subeutrophic) soils, is adapted to low temperatures, has high frost resistance, and low shade tolerance, and grows on high-nutrient soils rich in calcium and magnesium. Yole and others (1989) report very low nutrient status (oligotrophic to submesotrophic) for the soils of whitebark pine in the northern Coast Mountains. Soil pH and calcium content are given for whitebark pine soils in the Rocky Mountains by Baig (1972) and Smyth (1989a, 1989b). Approximately two-thirds of the soil profiles are calcareous and basic or circumneutral. Additional soil nutrient analyses (N, P, K, Ca, Mg, SO_4, and CEC) have been made by Smyth (1989a, 1989b).

STAND COMPOSITION

Throughout the Rocky Mountains, Columbia Mountains, and the Interior Plateau, whitebark pine forms stands with Engelmann spruce, subalpine fir, and the successional lodgepole pine. Occasionally, whitebark pine may extend to lower elevations in contact with hybrid spruce, in the Rocky Mountains and Selkirk Mountains. Although whitebark pine is sympatric with alpine larch in the southern Rocky Mountains, southern Purcell Mountains, and Cascade Mountains, the two species rarely form mixed stands, because they occupy different habitats. Generally, whitebark pine grows on drier, well-drained, southerly and westerly slopes, with shallow snow cover; in contrast, alpine larch occupies more mesic habitats with finer soils, on northerly and easterly slopes, and in deep snow accumulation areas. The geographic range of whitebark pine also overlaps with limber pine (*Pinus flexilis*) in the southern Rocky Mountains of Alberta and British Columbia. However, the two species are ecologically separated; limber pine grows at lower elevations in the foothills and front ranges well below the occurrence of whitebark pine.

In the Coast Mountains and the Cascade Mountains, whitebark pine forms stands with mountain hemlock, subalpine fir, Engelmann spruce, and lodgepole pine. In these mountains, whitebark pine may grow adjacent to stands with Alaska-cedar (*Chamaecyparis nootkatensis*) and Pacific silver fir (*Abies amabilis*), although they do not form mixed stands. In the northern Coast Mountains, the stands have an open canopy of whitebark pine, subalpine fir, lodgepole pine, and mountain hemlock, with seedlings and regeneration of all of these species (Pojar 1989; Yole and others 1989). In the northern Selkirk Mountains, whitebark pine also grows with mountain hemlock, subalpine fir, and hybrid spruce.

VEGETATION TYPES

There is considerable diversity in the species composition of whitebark pine stands. Whereas forest-line and tree-island stands appear discrete and clearly demarcated, the highest timberline stands have very open vegetation with widely spaced plants and widely spaced krummholz and dwarf trees. Problems arise in the delineation of such stands, and decisions may be difficult as to whether a patch of vegetation is part of a krummholz colony or a separate entity within a vegetation mosaic of krummholz and alpine meadow or krummholz and alpine heath.

One of the widespread whitebark pine vegetation types is the *Juniperus communis* series of dry habitats. Some of the major associated species are russet buffaloberry (*Shepherdia canadensis*), shrubby cinquefoil (*Potentilla fruticosa*), and bearberry (*Arctostaphylos uva-ursi*). This vegetation is widespread in the Rocky Mountains of Alberta (Baig 1972; Corns and Achuff 1982) and British Columbia (Achuff and others 1984a; Kuchar 1978; Lea 1984a, 1984b; Smyth 1987, 1989b). This vegetation also occurs in the southern Selkirk, Monashee, and Cascade Mountains, and in the Chilcotin Range of the east slope of the southern Coast Mountains (Selby 1980; Selby and Pitt 1984). A series of floristically related communities, also in dry habitats, occurs in the southern Rocky Mountains: the *Shepherdia canadensis* type (Lea 1984a, 1984b), the *Arctostaphylos uva-ursi* type (Smyth 1987, 1989b), and the *Festuca scabrella* type (Smyth 1987, 1989b).

Another widespread series of vegetation types are the heath communities of mesic, snow-accumulation habitats. The *Vaccinium scoparium* vegetation type occurs in the Rocky Mountains of Alberta (Baig 1972; Corns and Achuff 1982; Kuchar 1978; Ogilvie 1963, 1978a, 1978b) and adjacent British Columbia (Krajina 1969; Lea 1984a, 1984b; Smyth 1987). The *Phyllodoce glanduliflora, P. empetriformis* vegetation is common in the Rocky Mountains (Achuff and others 1984a; Baig 1972; Ceska 1989a, 1989b; Corns and Achuff 1982; Krajina 1969; Kuchar 1978; Ogilvie 1963, 1978a, 1978b) and in the Selkirk Mountains (Achuff and others 1984b). The *Cassiope mertensiana* vegetation type occurs in the Rocky Mountains (Achuff and others 1984a; Baig 1972; Ceska 1989a, 1989b; Krajina 1969; Kuchar 1973, 1978; Ogilvie 1963, 1978a, 1978b) and in the Selkirk Mountains (Achuff and others 1984b). The *Vaccinium membranaceum* vegetation type occurs in the Rocky Mountains (Achuff and others 1984a; Baig 1972; Corns and Achuff 1982; Kuchar 1978) and in the Selkirk Mountains (Achuff and others 1984b). A distinctive lichen community occurs on the east slope of the northern Coast Mountains. *Cladina rangiferina* and *Cladonia* spp. form the main ground cover under a sparse shrub layer with *Vaccinium membranaceum* and *Cassiope mertensiana* (Pojar 1978, 1989; Yole and others 1989).

The distinctive *Xerophyllum tenax* vegetation type occurs in the Rocky Mountains of southwestern Alberta (Baig 1972; Kuchar 1973; Ogilvie 1963, 1978a) and adjacent southeastern British Columbia. The *Dryas octopetala* vegetation type in wind-exposed, snow-free habitats is described from the southern Rocky Mountains of British Columbia (Lea 1984a, 1989b).

Within the subalpine and forest-line zone the *Rhododendron-Menziesia* vegetation type occurs in the southern Rocky Mountains of Alberta (Kuchar 1973) and southeastern British Columbia (Lea 1984a, 1984b) and in the northern Rocky Mountains of British Columbia (Ceska 1989a, 1989b). The tall willow-forb (*Salix* spp.-*Valeriana*) vegetation types are reported from the Rocky Mountains of Alberta (Baig 1972) and southeastern British Columbia (Kuchar 1978; Lea 1984a, 1984b).

PALEOECOLOGY

In a review of the main species encountered in the late Quaternary pollen record, Ritchie (1987) discussed the problem that none of the five western Canadian pines can be identified at the species level. Although our five-needle pines—whitebark pine, limber pine (*Pinus flexilis*), and western white pine (*P. monticola*)—have the distinctive *Haploxylon* pollen, they are not separable at the species level. Macrofossils are the only means of species identification. Until recently there had been no paleobotanical record of whitebark pine in western Canada.

In 1987, John Clague and Rolf Mathewes found buried logs of whitebark pine on the eastern slope of the southern Coast Mountains in British Columbia (Clague and Mathewes 1989; Mathewes 1988; Mathewes and Clague 1989). The age of the logs ranges between 8,200 to 9,100 yr. B.P., and associated with the logs are pollen and macrofossils of russet buffaloberry. The logs occur between 60 and 130 m above the present timberline, indicating a higher timberline and warmer climate at that time.

FUTURE STUDIES

As mentioned in the introduction to this paper, very little research has been done specifically on whitebark pine in western Canada. Research in most areas is needed for better understanding of this species.

The diversity of growth forms at timberline warrants attention. Population studies are required to determine the occurrence of altitudinal, latitudinal, geographic, and coastal versus continental races and ecotypes. Demographic analyses of whitebark pine stands are needed to understand its growth dynamics in relation to other timberline species, as well as to provide basic information for stand management. Soil chemistry studies are required to ascertain the relationship of whitebark pine to soil nutrients and to specific substrates such as limestone. Knowledge of the behavior of whitebark pine at the extremities of its range—in the Coast Mountains and in the northern Rocky Mountains and Interior Plateau—is of special interest since it can provide insight into the primary factors governing whitebark distribution and habitat relations.

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SESSION 3

Ecology of Whitebark Pine Forests

Steve Arno and David Mattson
Session Coordinators

This session provided state-of-the-art physical and biological information about the high-mountain ecosystems of whitebark pine. Included are papers describing geology, climate, fire, succession, seeds and seedlings, insects and diseases, ecological interactions of birds, squirrels, and grizzly bears, and modeling. Invited and volunteer papers provide a surprising amount of qualitative and quantitative information about high-mountain ecosystems and serve as the basis for management implications in the session that follows.

GEOLOGY, GEOMORPHOLOGY, AND SOILS WITHIN WHITEBARK PINE ECOSYSTEMS

Katherine Hansen-Bristow
Clifford Montagne
Ginger Schmid

ABSTRACT

Whitebark pine (Pinus albicaulis) *stands grow on a variety of soil parent material lithologies (crystalline, volcanic, sedimentary [sandstone, argillite, limestone, interbedded sandstone and shale]) and surficial materials (glacial till, mass failure, colluvium, and residuum). The distribution of whitebark pine on calcareous parent materials appears to be limited to the Northern Rocky Mountains, from Canada into southern Montana.*

Landforms within whitebark pine ecosystems result from the interaction of bedrock type and structure with surficial processes of mountain environments (freeze-thaw, mass failure, mass wasting, and glaciation). Those landforms include ridge tops and dissected mountain slopes, glacial trough walls and moraines, cirque headwalls and basins, landslides, hogback ridges, talus slopes, rock glaciers, and rock slides. In most cases, whitebark pine is found on landforms with good drainage and relative stability.

Because of severe climate that limits biological activity, soils of whitebark pine ecosystems are minimally developed and highly influenced by underlying parent material. Soil textures range from sandy to loamy and fine loamy, often with abundant rock fragments (skeletal). Soil reaction is usually acidic, except on calcareous substrates. Many of these soils are classified as Cryochrepts and Cryoboralfs. Nutrient levels may generally be low in comparison with most forest soils.

INTRODUCTION

Whitebark pine (*Pinus albicaulis*) ecosystems are found predominantly at the highest elevations of forest growth, a result of the ability of this pine to tolerate the harsh climate at elevations where other tree species are not as dominantly competitive. Within these high elevations the precise location of whitebark pine stands is partially determined by the sites' geology, geomorphology, and soils.

Paper presented at the Symposium on Whitebark Pine Ecosystems: Ecology and Management of a High-Mountain Resource, Bozeman, MT, March 29-31, 1989.

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This paper will provide generalized, cited information on the geology, geomorphology, and soils of high elevations of western North America where whitebark pine ecosystems may occur. Specific field and laboratory data from previous studies illustrate geologic, geomorphic, and soils relationships. Data have been cited from habitat and cover type maps of the Gallatin National Forest, Forest Service, U.S. Department of Agriculture, soil surveys, and from communication with staff of the Beaverhead, Bridger-Teton, Deerlodge, Flathead, Kootenai, and Gallatin National Forests. Literature searches provided relevant sources of data; however, there is little published material on this subject.

GENERAL GEOGRAPHY

In the Rocky Mountains, whitebark pine extends from British Columbia and Alberta, through Montana, Idaho, and Utah, to the Wind River Range in Wyoming. Whitebark pine also extends from the British Columbia coastal ranges through the Cascade and Sierra Nevada ranges. It occurs in isolated mountain ranges in Nevada, California, Oregon, and Washington (Arno and Hoff 1989) (fig. 1).

The high-elevation settings in which whitebark pine ecosystems are found are characterized by geography common to many mountain environments. Specific distributional information is available for selected stands within the general range of whitebark pine (table 1). As shown, whitebark pine is found on a wide variety of aspects and on wide-ranging slopes. In accordance, however, with expected latitudinal controls on the elevation of upper treeline species, the pine is found at highest elevations in the southern sites of the Sierra Nevada and the Bridger-Teton National Forest, WY. At more northerly locations, the pine's upper elevational limit may be depressed by both snow and lower energy budgets, resulting in its lower distribution.

At many tree-line and tree-limit sites, trees reach their maximum elevational limits on convex rather than concave slopes. Nocturnal temperature inversions often produce inverted tree lines at concave sites; in contrast, convex sites may have a warmer microclimate that extends the length of the growing season (Hansen-Bristow 1986). In some of the harshest microclimates, however, the uppermost trees are found at slope concavities where

Figure 1—The distribution of whitebark pine illustrates its widespread occurrence in western North America (from Arno and Hoff 1989).

Table 1—Available data on some site characteristics of some whitebark pine stands (derived from Baig 1972; Clausen 1965; Holland and Coen 1982; Lueck 1980; Steele and others 1983; Winthers 1989)

Site	Slope	Aspect	Elevation
	Percent		*m (ft)*
Banff and Jasper National Parks, Canada			
- whitebark dominated	10-75	NW to NE SW to SE	2,000-2,280 (6,560-7,480)
- whitebark codominant or subdominant	37-70	Wide variety	1,720-2,320 (5,645-7,610)
Flathead National Forest, MT	20-90	NE	1,675-2,440 (5,500-8,000)
Gallatin National Forest, MT	0-45	Wide variety	2,075-2,620 (6,810-8,600)
Bridger-Teton National Forest, WY	5-90	S and W	2,400-3,050 (7,875-10,000)
Cascade Mountains (Bachelor Butte, OR)	—	Wide variety	2,350-2,530 (7,710-8,300)
Sierra Nevada Mountains (Slate Creek, CA)			
- whitebark dominated	—	N	3,050-3,190 (10,010-10,456)
		S and E	3,200-3,350 (10,500-10,990)
- whitebark subdominant		S and E	3,050-3,200 (10,010-10,500)

winter snow accumulation provides insulation and protection from wind-blown ice crystals and winter desiccation. These snow-accumulation sites also provide moisture for growth. Because pines illustrate a superior adaptation to unshaded sites (more drought and radiation tolerant) (Wardle 1974), they often play a pioneering role at high elevations, occupying open meadow sites. They often serve as nuclei for establishment of other tree species. Such is the case at Logan Pass, MT, within Glacier National Park, where old whitebark pines, surrounded by younger subalpine fir, have formed "tree islands" (Habeck 1969).

GENERAL GEOLOGY, GEOMORPHOLOGY, AND SOILS

The lithology and structure of rock within a mountain environment tend to control landscape development (through the resistance and strength of its constituent material) and, therefore, influence a site's potential to support tree growth. Outliers and ridges are often associated with resistant crystalline rocks, such as granite or quartzite, while valleys may more often be formed in weak and friable rocks, such as limestone or shale (Price 1981).

Lithology—Mountains with whitebark pine include a variety of geologic types. The Cascades of Oregon and Washington are primarily volcanic while the Sierra Nevada is primarily igneous. Many of the mountains found in the continental interiors, such as much of the Central Rocky Mountains, are composed of ancient crystalline cores of Precambrian rock. Other ranges, such as the Northern Rocky Mountains, are composed chiefly of marine sediments, which have often been metamorphosed and injected with volcanic material. Coarse-textured bedrock lithologies often predominate. Where there are fine-textured lithologies, the surficial geologic materials usually have abundant coarse rock fragments. Acidic rock types are more prevalent than basic rock types.

Structure—A variety of geologic structures are found in environments occupied by whitebark pine. For example, the Northern Rocky Mountains are a major folded and faulted range, as exemplified by Montana's Lewis Overthrust in which Precambrian sedimentary rocks were uplifted and thrust over younger shales and sandstones. The Basin and Range mountains of the western United States result from tensional forces stretching the earth's crust and creating abrupt and spectacular fault scarps. The Sierra Nevada provides an example of a faulted range, dipping gently to the west, while the east-facing slopes rise abruptly as a fault line scarp.

Geomorphology

The landscapes of whitebark pine are influenced by both constructive and destructive processes and, therefore, these high-elevation sites are often characterized by a high rate of energy transfer, particularly where steep slopes prevail. Additionally, the type and rate of geomorphic processes are affected by the structure, form, climate, and composition of a particular mountain range. These factors result in a wide variety of environments and landscapes for whitebark pine.

Process—The high-mountain landscape is characterized by instability, variability, rapid physical weathering, and a continual transport of earth materials downslope. Many geomorphic processes are intensified in areas with steep slopes and a mountain-type climate. Low temperatures tend to be the dominant climatic feature at higher elevations, producing landscape regimes that are glacial, nivational, and periglacial (Embleton and King 1974; Price 1972; Washburn 1973).

Although many scales of geomorphic processes operate in mountains, large-scale features such as mudflows, landslides, and avalanches can reach catastrophic dimensions and do more geomorphic work in a matter of minutes than day-to-day processes can accomplish in centuries (Price 1981; Rapp 1960; Rapp and Fairbridge 1968). These processes often create both suitable and unsuitable sites for tree growth. For example, an avalanche slope is generally unsuitable for tree growth due to snow movement (Rapp 1959) and enhanced downslope drainage of cold air. In contrast, debris piles at the base of the avalanche slope may provide a shaded habitat for seedling survival.

Glaciation—Glacial processes, directly shaping the land with ice movement, produce some of the most distinctive and striking landscapes in the world. In sites where glacial erosion has occurred, such as bare cirque walls, trees are generally excluded. In contrast, soils on glacial and glacio-fluvial deposits often provide potential habitat for successful tree establishment and survival (Price 1981).

Periglacial—The entire periglacial system, characterized by low temperatures, frost action, mass wasting, and nivation, occupies large areas of mountain landscapes at high elevations, and is a dominant influence on whitebark pine distribution. Periglacial processes such as frost action (freezing and thawing of earth surfaces) form patterned ground (sorted and nonsorted circles, polygons, nets, steps, and stripes), and blockfields. Generally these landform surfaces are quite unstable, often to the point of elimination or prohibition of vegetative cover.

Mass wasting, achieving its greatest development in mountain landscapes because of steep slopes, great relief, and environmental variability, is the downslope movement of material due to gravity without the aid of a specific transporting medium (Price 1981). Many landforms resulting from mass wasting are the product of more than one type of motion, including creep, solifluction, mudflows, slumps, rockfalls, landslides, and debris avalanches, and often are unstable to the point of exclusion of trees.

Nivation, erosion within the narrow zone of the snowline area, creates hollows and depressions on the landscape. In many areas, benches, terraces, and rounded or flattened summits (altiplanation or cryoplanation terraces) are attributed to nivational processes (Price 1981). These processes often create more diverse microsites suitable for tree establishment due to substrate accumulations or shelter, once active erosion and deposition have ceased.

Soils

Soil development processes are functions of Jenny's Five Factors of Soil Formation (Jenny 1941)—climate, biological activity, relief or landscape position, geologic parent material, and time. High-elevation climates of whitebark pine ecosystems severely limit both biological activity and chemical weathering. Due to their position within usually mountainous landscapes, whitebark pine soils often occupy steep-slope landscape positions where erosion of various forms is the predominant surficial process. As mentioned earlier, many of the geologic parent materials at high elevations in western North America tend to produce coarse, sandy-textured, rock-fragment-rich soils. The bedrock chemistry is usually acidic. Due to landscape position, whitebark pine soils often occupy less stable slope positions where erosion predominates; therefore, soils of whitebark pine ecosystems tend to be young and minimally developed.

The five factors of soil formation limited by climate, biological activity, and coarse-textured geologic parent materials interact to produce minimally developed soils that are often low in plant-available water-holding capacity and nutrients. Whitebark pine soils are most often classified as Cryochrepts (cold-climate soils with light-colored surface horizons and minimally developed subsurface horizons). In some cases, whitebark pine soils are Cryoboralfs (cold-climate soil with light-colored surface horizons and clay accumulation in a subsurface horizon), Cryorthents (minimally developed cold-climate soils), or Cryoborolls (cold-climate soils with dark, organic-matter-enriched surface horizons) (Kuennen 1989).

GEOLOGY OF SPECIFIC ECOSYSTEMS

In Banff and Jasper National Parks of the Canadian Rockies, both calcareous (limestone and dolomite) and noncalcareous (sandstone, shale, siltstone) parent materials support whitebark pine (Baig 1972; Holland and Coen 1982). Many of the stands found in northwestern Montana are found in the Belt Supergroup, which includes metasediments of argillite, siltite, quartzite, and limestone. In southern Montana (Gallatin National Forest), whitebark pine stands are found on a variety of parent materials, including crystalline, volcanic, and sedimentary rocks (table 2) (fig. 2). Eighty-five percent of the whitebark pine stands sampled by Weaver and Dale (1974) in central and southern Montana were on igneous parent materials. In northern Wyoming, whitebark pine is found on a variety of bedrock types, including quartzite, sandstone, limestone, and dolomite.

A question exists concerning the distribution of whitebark pine and limestone substrates. Weaver and Dale (1974) commented that whitebark pine is definitely not found on limestone substrates, with the exception of its occurrence on Wheeler Ridge, near Bozeman, MT. In the Gallatin National Forest soil survey, 11 percent of the acres are mapped in *Abies lasiocarpa/Pinus albicaulis* habitat types (9.5 percent) and *Pinus albicaulis/Abies lasiocarpa* habitat types (1.5 percent). Limestone is associated with 11.5 percent of the mapped acres, but only 1.5 percent of the acreage has *Abies lasiocarpa/Pinus albicaulis* habitat types and limestone. *Pinus albicaulis/Abies lasiocarpa* habitat types are not found associated with limestone. Arno's work (referred to in Pfister and others 1977) also indicated whitebark pine is not found on limestone. Whitebark pine is, however, found on limestone in the Canadian Rockies (Baig 1972; Holland and Coen 1982), the Flathead National Forest (Martinson and Basko 1988), and in the Bridger-Teton National Forest (Winthers 1989). Bamberg and Major (1968) mentioned stone pine (*Cembrae* or stone pine is a subsection of *Pinus*; it includes *albicaulis*) on calcareous parent material at three Montana locations: the Big Snowy Mountains, Siyeh Pass in Glacier National Park, and the Flint Creek Mountains. Whitebark pine also grows in limestone-derived soils in the Gravelly Range of southwestern Montana (Svoboda 1989). This relationship needs further study.

Figure 2—A whitebark pine stand in the Gallatin National Forest on metamorphic parent rock materials.

Table 2—Characteristics of Gallatin National Forest soil map units with whitebark pine as a habitat type species (PIAL-ABLA is *Pinus albicaulis-Abies lasiocarpa* habitat type, ABLA-PIAL/VASC is *Abies lasiocarpa-Pinus albicaulis/Vaccinium scoparium* habitat type) (from Davis and Shovic 1984)

Habitat type (percent of map unit)	Landform	Parent material	Slope	Aspect	Elevation	Soil classification
			Percent		*m* (*ft*)	
PIAL-ABLA (10-50)	Glacial troughs Cirque headwalls	Hard crystalline rocks	45+	Variable	2,500+ (8,200+)	Dystric and typic cryochrepts
PIAL-ABLA (5-30)	Talus slopes Rock glaciers Rock slides	Undifferentiated mixed colluvium	20-45	Variable	2,130-2,990 (7,000-9,800)	Rubble land
PIAL-ABLA (10-20)	Cirque basins	Hard crystalline rocks	0-20	E-NW	2,590+ (8,500+)	Dystric and litic cryochrepts
ABLA-PIAL/VASC (80)	Moraines	Glacial till-hard crystalline rocks	0-20	Variable	2,315-2,590 (7,600-8,500)	Dystric cryochrepts
ABLA-PIAL/VASC (80)	Moraines	Glacial till-volcanic rocks	0-20	Variable	2,375-2,590 (7,800-8,500)	Mollic cryoboralfs
ABLA-PIAL/VASC (75)	Moraines	Glacial till-hard crystalline rocks	45+	Variable	2,375-2,590 (7,800-8,500)	Dystric cryochrepts
ABLA-PIAL/VASC (70)	Rounded ridgetops	Hard crystalline rocks	0-20	Variable	2,375-2,590 (7,800-8,500)	Dystric cryochrepts
ABLA-PIAL/VASC (70)	Rounded ridgetops	Volcanic rocks	0-20	Variable	2,375-2,590 (7,800-8,500)	Mollic cryoboralfs
ABLA-PIAL/VASC (65)	Dissected mountain slopes	Hard crystalline rocks	45+	Variable	2,070-2,500 (6,800-8,200)	Dystric cryochrepts
ABLA-PIAL/VASC (65)	Dissected mountain slopes	Volcanic rocks	45+	Variable	2,375-2,590 (7,800-8,500)	Mollic cryoboralfs
ABLA-PIAL/VASC (60)	Moraines	Glacial till-volcanic rocks	45+	Variable	2,375-2,590 (7,800-8,500)	Mollic cryoboralfs
ABLA-PIAL/VASC (60)	Dipslopes	Folded sedimentary rocks (ss and shale)	10-20	North	2,440-2,680 (8,000-8,800)	Typic cryoboralfs
ABLA-PIAL/VASC (55)	Landflows	Mass failure deposits-weathered volcanics	0-20	Variable	2,375-2,590 (7,800-8,500)	Typic and mollic cryoboralfs
ABLA-PIAL/VASC (50)	Landflows	Mass failure deposits-weathered soft sedimentary rocks	0-20	Variable	2,375-2,620 (7,800-8,600)	Typic aquic mollic cryoboralfs
ABLA-PIAL/VASC (50)	Moraines	Glacial till-soft sedimentary rocks Limestone	0-20	N-NE	2,440-2,590 (8,000-8,500)	Mollic cryoboralfs

GEOMORPHOLOGY OF SPECIFIC ECOSYSTEMS

The majority of sites dominated by whitebark pine in Banff and Jasper National Parks are on colluvial slopes. Where whitebark pine is found on moraines and landslide deposits, it is often codominant or subdominant with subalpine fir, Engelmann spruce, and lodgepole pine (Baig 1972; Holland and Coen 1982).

In northwestern Montana (Kootenai and Flathead National Forests) whitebark pine is often found on glacially scoured sites. It is found in both cirque basins and on bedrock-dominated sideslopes. In addition, the soils there are subject to frost churning (Kuennen 1989). As displayed in table 2, in south-central Montana whitebark pine seems to exist on nearly all mountain landforms including glacial cirque basins, troughs, headwalls, moraines, landflows, and both dissected mountain slopes and rounded ridgetops (fig. 3).

Figure 3—A ridge in the Gallatin National Forest, MT, provides the setting upon which whitebark pine exist.

SOILS OF SPECIFIC ECOSYSTEMS

Characteristics of general forest soils can be compared with soils of whitebark pine sites (table 3). The usually lower pH and percent base saturation of whitebark pine site soils may be due to acidic, coarse-textured parent materials. Higher organic matter levels of whitebark pine soils may be related to the cool, dry, and windy decomposition-limiting climates of high elevations.

Soil pedon descriptions are available for 24 whitebark pine sites within Banff and Jasper National Parks (Baig 1972; Holland and Coen 1983). Half of these are sites dominated by whitebark pine (for example, *Pinus albicaulis-Picea engelmannii* or *Pinus albicaulis-Abies lasiocarpa*). The other half are sites where whitebark pine is codominant (*Pinus albicaulis-Abies lasiocarpa* and *Pinus albicaulis-Pinus contorta*) or subdominant (for example, *Abies lasiocarpa-Picea engelmannii-Pinus albicaulis*; *Abies lasiocarpa-Pinus albicaulis*; *Picea engelmannii-Pinus albicaulis*). Neither study documented any stands that are pure whitebark pine. The soils at all these sites are shallow with limited profile development.

Table 3—Properties of soils in whitebark pine ecosystems

	General forest		Whitebark pine sites				
Soil properties	Gallatin NF, MT (Montagne and Munn 1980)	Gallatin NF, MT (Montagne and Munn 1980)	Montana and Wyoming (Weaver and Dale 1974)	Kootenai NF, MT (Kuennen 1989)	Wind River Range, WY (Reed 1976)	Banff and Jasper NP, AB (Holland and Coen 1983)	Banff and Jasper NP, AB (Baig 1972)
	[1]*n* = 335	*n* = 19	*n* = 19	*n* = 7	*n* = 5	*n* = 31	*n* = 31
Percent sand	42	54	42	(silt loams)	—	54	51
silt	34	34	35	49	—	38	35
clay	24	24	11	9	—	8	16
pH	6.2	5.4	5.4	5.1	5.1	6.2	6.5
OM (percent)	2.3	2.9	6.1	4.2	—	3.0	2.2
Total N (percent)	.09	.000	—	.095	—	—	—
Ca (meq/100 g)	10.7	3.5	1.3	.4	8.2	1.1	—
Mg (meq/100 g)	2.5	.84	.6	.1	1.8	.3	—
Na (meq/100 g)	0.2	.07	.48	.4	—	.1	—
K (meq/100 g)	0.5	.40	.30	.2	.7	.1	—
CEC (meq/100 g)	21.2	16.0	—	15.5	—	5.3	—
BS (percent)	61.0	25.8	—	6.0	45.8	—	—
EC (mmhos/cm)	.48	.82	0.3	.12	—	—	—

[1]*n* = number of horizons analyzed.

Those with the highest degree of horizonation are found on sites where whitebark pine is codominant or subdominant. At these sites both AE and AB horizons are identified. Depth to C horizons ranged from 8 to 46 cm (3 to 18 inches) on the sites dominated by whitebark pine, and from 0 to 90 cm (0 to 36 inches) on all other sites. Textures in all horizons are silt loams, or coarser, with a majority of horizons being sandy loams. All are considered well drained with at least 20 percent (by weight) coarse fragments. Soils at the sites dominated by whitebark pine are classified as Dystric Brunisols and Regosols (Orthic, Cumulic, and Lithic). The other sites are classified as Dystric and Eutric Brunisols and Orthic Regosols (Brunisols are equivalent to Inceptisols, Regosols to Entisols).

Pfister and others (1977) summarized soil properties of whitebark pine-associated habitat types of the Forest Service's Northern Region (Montana and Northern Idaho) (table 4). In the northern Region, whitebark pine establishes on soils of high-elevation, subalpine-climate landscapes that are usually low in clay (with exception of some soils in the Gallatin and Beaverhead National Forests) and high in rock fragments (fig. 4). These soils are Cryochrepts, Cryoboralfs (clay rich), Cryoborolls, and Cryandepts (if influenced by volcanic ash) (Holdorf 1989).

In the Kootenai National Forest of northwestern Montana, whitebark pine exists on Cryochrepts (Typic, Andic, and Lithic) and Cryandepts with loamy-skeletal textures of mixed mineralogy and relatively low pH (5.5 to 6.5) (fig. 5). Most of these soils have a volcanic ash-influenced surface layer found over metasedimentary residuum of the Belt Supergroup. Two example soils have horizons influenced by silt-loam volcanic ash found over gravelly and rocky subsoils. Levels of acidity (pH) range from 4.0 to 5.7 with a cation exchange capacity of 6 to 23 meq/100 g. Percent base saturations are 4 to 14 percent and the surface horizons have 5 to 8 percent organic matter. Amounts of extractable calcium, magnesium, sodium, and potassium are generally less than 1 ppm.

The Flathead National Forest draft soil survey (Martinson and Basko 1989) describes four mapping units within the upper subalpine forest that include whitebark pine. Like the Kootenai National Forest soils, these have volcanic ash surface layers, acidic pH's, and abundant coarse fragments. In these whitebark pine landscapes the cirque basins have Andic Cryochrepts (fig. 5) in soil accumulation positions and Entic Cryandepts (fig. 6) on the steeper sites. Whitebark pine-subalpine fir is the major habitat type, occupying over 35,615 ha (88,000 acres). The bedrock-dominated sideslopes have over 3,640 ha (9,000 acres) of mixed forests of whitebark pine, subalpine fir, Engelmann spruce, and lodgepole pine, with subalpine fir-whitebark pine/grousewortleberry as the major habitat type. Soils are Ochrepts consisting of volcanic-ash-influenced silt-loam surface horizons over bedrock.

Weaver and Dale (1974) summarized soil properties for 19 whitebark pine stands found mostly in central and southern Montana. These were thin soils, with a median pH of 5.4 and loam to silt-loam textures with low clay content (average clay, 8.5 percent). These soils have average extractable nutrient amounts of: P, 153; K, 121; Ca, 260; Mg, 72; and Na, 110 (in ppm).

Table 4—Soil properties of whitebark pine habitat types, Northern Region, Forest Service (Pfister and others 1977)

	Habitat type		
	ABLA-PIAL/VASC	PIAL/ABLA	PIAL
	(n = 22)	(n = 15)	(n = 5)
Mean percentage surface rock	4	13	2
Mean percentage bare soil	1	6	3
Mean pH of upper soil	5	4.9	6
Mean percentage gravel	26	45	25

Figure 4—Whitebark pine is found in Montana and Idaho on soils that are usually low in clay and high in rock fragments.

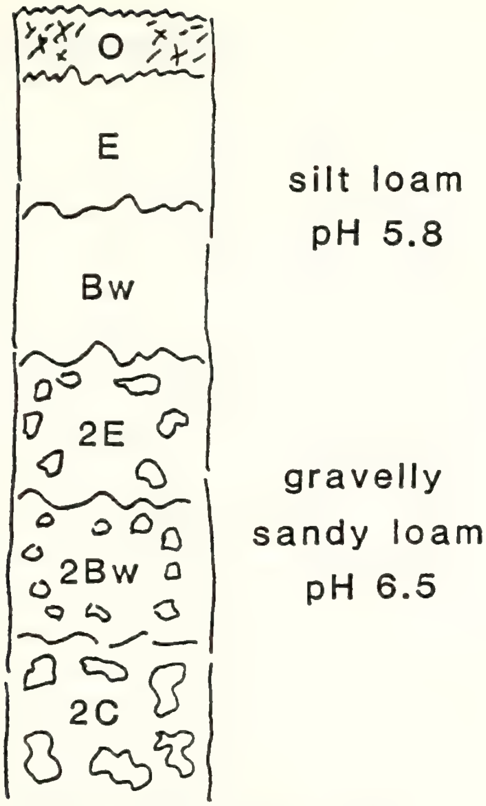

Figure 5—A typical soil profile of whitebark pine stand in the Kootenai National Forest, MT (typical soil classification is an Andic Cryochrept, loamy-skeletal, mixed).

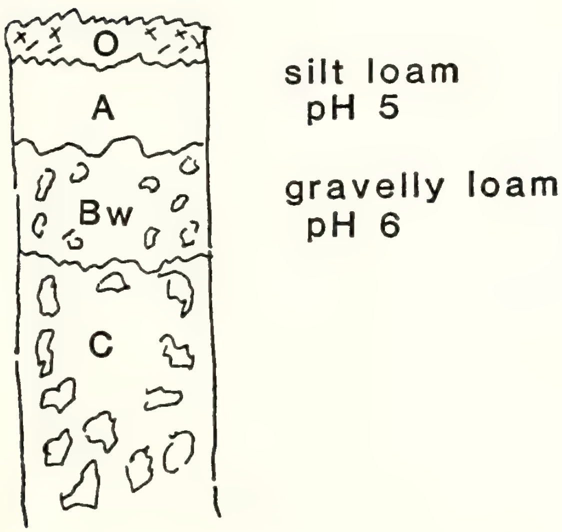

Figure 6—A typical soil profile of an Entic Cryandept.

The Gallatin National Forest soil survey (Davis and Shovic 1984) described soils in three whitebark pine-associated habitat types (table 5) reflecting the variety of bedrock parent materials within that forest. Dystric Cryochrepts (moderately acidic) are found on Precambrian crystalline rock, while volcanic and sedimentary parent materials develop more base-rich and more clay-rich Alfisols (Mollic and Typic Cryoboralfs) and Mollisols (Argillic and Typic). These sites have short growing seasons (most with less than 50 frost-free days) and may be droughty in summer.

The Beaverhead National Forest in southwestern Montana has whitebark pine on both clayey limestone (Mollic Cryoboralfs in the Gravelly Range) and nonlimestone-derived soils. Other whitebark pine sites have acidic soils (Dystric Cryochrepts) formed in glacial till and in residuum from sandstone, gneiss, and granite (Svoboda 1989).

In the Wind River Range at the southeastern limit of whitebark pine (Steele and others 1983), whitebark pine habitat types are found on coarse (sandy loam), rock-fragment-rich, Typic or Lithic Cryochrepts. These soils are developed on parent materials of residuum and glacial till from granitic and gneissic bedrock. Average soil pH's for these three habitat types range from 5.6 to 6.2.

In the Bridger-Teton National Forest south of Jackson, WY, whitebark pine habitat types occupy soils that are developed in slope-wash mantles over residuum and bedrock. Map units are complexes of Alfisols

Table 5—Properties of soils associated with whitebark pine in the Gallatin National Forest, MT (from Montagne and Munn 1980)

	Habitat type ABLA/PIAL	Habitat series ABLA/PIAL	Habitat type groupsDystric Cryochrepts in habitat groups with PIAL
	(*n* = 12)	(*n* = 15)	(*n* = 19)
Bulk density	1.34	1.35	1.3
Percent sand	35	43	54
Percent silt	45	40	39
Percent clay	20	17	11
Available water (cm)	3.8	3.4	2.8
Percent organic matter	2.6	2.8	2.9
pH	6.7	6.4	5.4
Cation exchange capacity (meq/100 g)	20	19	16
N (total percent)	0.07	0.057	0
P (available ppm)	148	120	90
K (extractable ppm)	176	156	155
Ca (extractable meq/100 g)	14	11.1	3.5
Mg (extractable meq/100 g)	1.6	1.3	0.84
Percent base saturation	56	46	26

(Mollic Cryoboralfs), Inceptisols (Typic Cryochrepts), and Mollisols (Typic Cryoborolls), all with a loamy-skeletal, mixed mineralogy. These soils are gravelly to very cobbly loams with pH's mostly near 6, but as high as 8.

SUMMARY

The distribution of whitebark pine at upper timberline is influenced, to some degree, by the geology, geomorphology, and soils of these high-elevation environments. Whitebark pine is found on a variety of geologic parent materials including sedimentary deposits, crystalline metamorphics, and volcanics. Presence of the pine on calcareous parent material appears to be limited to the northern extent of whitebark pine distribution in North America.

The landforms of whitebark pine environments are influenced by mountain building and high-elevation surficial processes. Whitebark pine grows on a variety of slope angles and aspects. Soils under whitebark pine tend to be shallow with minimal horizon development and are classified mainly as Cryochrepts and Cryoboralfs. Whitebark pine soils are predominantly coarse textured with an abundance of coarse fragments and low nutrient levels. These soils will be acidic except in northern areas where whitebark pine is found on calcareous substrates.

The information presented in this paper has been gathered from a review of published whitebark pine studies and through contact with Forest Service personnel. There is minimal information compiled about the soil-related environment of whitebark pine. We hope the summarization presented here will help direct further research on the geology, geomorphology, and soils of whitebark pine.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from Ray W. Brown)—The soils and geologic materials you described were similar to severely disturbed sites at high elevations (especially in the Beartooth Mountains of Montana and Wyoming and in the Rocky Mountains of Colorado) where *P. albicaulis* is absent. Would you be willing to say, in view of the types of geologic materials and soils that whitebark pine grows on, that this species is early successional and that it may be useful in revegetation as a colonizer?

A.—We agree that the soils and geologic materials upon which whitebark pine is found are very similar to those at disturbed high-elevation sites (they are young, thin, often rocky, and relatively nutrient poor). We further agree that this species may be early successional at these sites, and may even maintain itself as a pure stand at its upper most elevations. Because there is a critical need to revegetate and rehabilitate many severely disturbed sites at high elevations, we recommend a strong emphasis be placed on research aimed toward successful artificial planting and use of whitebark pine as a colonizer in these areas. This effort will require a detailed study of the specific site characteristics where the pine is naturally regenerating, of the seed germination requirements of the pine, and of techniques of planting that will assure establishment and survival.

Q. (from Stephen Harvey)—How about presenting elevation as "elevation below timberline," thereby avoiding latitude problems?

A.—Actual elevational occurrences provide the important perspective of the influences of latitude (radiation budgets and snow influence, in particular) on the geographic extent of whitebark pine. Presenting elevation as "elevation below timberline" would be useful for understanding the local extent of the pine; however, much of the data on the elevation of timberline are either lacking or have been determined by a variety of means. For example, timberline has been defined as the upper unit of trees greater than 2 m tall, as the upper limit of sexual reproduction, and as the extreme upper limit of tree growth. This variety of interpretations leads often to erroneous comparisons of studies.

Q. (from Friedrich-Karl Holtmeier)—With regard to microbial activity and to the pedo-ecological conditions, it would be interesting to learn something about the C/N ratio. Did you investigate this point? If yes, what were the results?

A.—Carbon-nitrogen ratios could provide some interesting insights into soil pedogenic conditions in whitebark pine ecosystems. None of the data available to us, however, included C/N ratios, so we were unable to investigate this relationship. Further research with whitebark pine soils should consider the importance of C/N ratios.

CLIMATES OF SUBALPINE PINE WOODLANDS

T. Weaver

ABSTRACT

The climate of whitebark pine (Pinus albicaulis) *woodlands is generally cold (average daily maxima and minima in January are –2 and –11 °C, respectively) and snowy 1 to 3 m maximum pack) in winter and warm (July average temperatures are 21 and 4 °C, respectively) and dry (July to September precipitation averages 102 mm and individual months can be rain free) in summer. The tree's lower altitudinal limit probably is set by the competition of trees better able to compete for necessary resources such as light, water, and nutrients. In contrast its upward extension may be limited zonally by summer frosts and locally by desiccation. While the presence of one stone pine species is apparently a good indicator of an equivalent climate for other stone pine species, its presence does not indicate an identical climate and may therefore not indicate an equivalent climate for nonpine species with different climatic requirements.*

INTRODUCTION

Climate is a major determinant of plant (or community) presence, and due to this linkage, particular climax communities suggest particular climates and vice-versa. Extant vegetation and climatic data cannot, however, predict each other perfectly because other factors also affect dominance; these include propagule availability, substrate, biotic (for example, grazer or pathogen) or abiotic (for example, fire or windthrow) disturbance, and time. While they are less than universal, good predictions can be had by stratifying out the confounding factors one by one, that is, by focusing on one biotic region, one substrate, only undisturbed stands, and only mature stands.

Plant or community indicators of climate have been useful historically to new settlers of unexplored, undisturbed, and uninstrumented areas. And they are still useful in areas too complex to instrument economically. Climate-vegetation relationships have been studied at the world and continental levels by ecologists including Clements (1916), Holdridge (1947), Schimper (1903), Walter (1973), Walter and others (1975), and Whittaker (1975). The work is naturally extended to mountain regions where managers wrestle with moderately large land units containing "a world of variation." Work relevant to the Northern Rocky Mountains includes that of Baker (1944), Callison and Harper (1982), Daubenmire (1956), Harper and others (1980), Holdridge (1947), Price and Evans (1937), and Weaver (1980).

This paper describes and compares climates of pine woodlands near timberline. Its objectives are: (1) to characterize the climate of whitebark pine (*Pinus albicaulis*) communities with respect to factors important to the tree and its associates, (2) to compare the climate of whitebark pine woodlands with those of communities immediately above and below them with the object of generating hypotheses to explain the distribution of each type, and (3) to compare the whitebark pine climate with the climates of Eurasian stone pines as a test of the hypothesis that stone pine woodlands indicate similar climates worldwide.

METHODS

The climates of whitebark pine woodlands were characterized by summarizing data (CDOT 1961-70; Leeson 1989; Losleben 1983; and USDC 1951-80) collected in stands representative of the community. The temptation to include data from stations not in whitebark pine woodlands, but in some imagined "whitebark zone," was resisted because the heterogeneity of high-altitude microclimate makes it probable that such data would misrepresent the vegetation studied. While use of a longer record would have been desirable, data were summarized for 10 years, because few stations have a longer record and use of the same record length facilitates comparison of extremes. Ecologists consulted on the choice of stands are listed under "Acknowledgments." Data from Kings Hill, MT, Crater Lake, OR, and Old Glory Mountain, BC, were complete. Temperature data were unavailable from Ellery Lake; thus I violated my approach and substituted temperature data from a site (White Mountain I = Crooked Creek [3,123 m]) without whitebark pine, but with similar latitude, longitude, and altitude, and a more continental climate. Data from the Sunshine Station at Banff were gathered for avalanche forecasting, and only those from 1978 were sufficiently complete for my application.

Whitebark pine climates are contrasted with those of adjacent vegetation types. Instrumented subalpine fir environments with occasional or seral whitebark pine appear at Yellowstone Lake, WY, and Cooke City, MT (Despain and Rankin 1989). Alpine stations would ideally be paired with whitebark woodland sites from the same region—as the Lake or Cooke and Kings Hill sites almost are—but no data from alpine stations other than Niwot Ridge, CO, and White Mountain, CA, were available.

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While White Mountain II (Barcroft, 3,837 m) temperature data probably represent conditions above whitebark krumm- holz reasonably, the White Mountains are far drier than mountains usually containing whitebark pine. Data from Niwot Ridge, CO, undoubtedly represent conditions above whitebark krummholz better (Billings 1989).

Climates of environments dominated by closely related stone pines (Lanner, this proceedings; Mirov 1967) were compared with those of whitebark pine by summarizing data from stations in those types. Decade-long data sets from three *Pinus cembra* sites were supplied by Tranquillini (1989). Since *Pinus sibirica* and *Pinus pumila* occupy more homogeneous "plains areas," I felt reasonably confident in summarizing data from stations chosen with the help of Critchfield and Little (1966), Lieth (1988), and Mirov (1967). Stations used to represent *Pinus sibirica* were Serov (24), Surgut (28), Kolpasevo (30), Jenisejsk (32), Irkutsk (34), Tura (41), Kirensk (47), and Krasnojarsk (73). Stations used to represent *Pinus pumila* were Anadyr (13), Apuka (14), Petropavlovsk-Kamcatskij (37), Vitujsk (48), Jakutsk (49), Verchojansk (51), Ochotsk (53), and Zyranka (54). The numbers following each place name indicate the station number in Muller's (1982) compendium of climatic data.

Some climatic parameters were studied as indices of "killing conditions." Absolute maximum and minimum temperatures and absolute maximum and minimum monthly precipitation recorded in a decade suggest long-term values, but these undoubtedly underestimate extremes experienced by long-lived trees (Gumbel 1954).

Other parameters are reported as indices of average conditions likely to have a greater influence on the performance (for example, photosynthesis, respiration growth, and seed yield) of established trees: mean monthly maximum and minimum temperatures, mean annual precipitation, and mean summer (July to September) precipitation. While data from a 10-year record are minimal for estimating extremes, a decade of observations should reasonably represent average conditions.

RESULTS

Data for describing extreme conditions in the climates of three whitebark pine woodlands (Ellery Lake, CA, Crater Lake, OR, and Kings Hill, MT) and two krummholz stands (Old Glory, BC, and Banff, AB) are presented in table 1. The seasonal progression of temperature and precipitation data for one woodland (Kings Hill) and one timberline (Old Glory) site are presented graphically in figures 1 and 2.

Data comparing the climates of sites in which whitebark pine woodlands are climax with forest sites below them and alpine tundra sites above them also appear in table 1. Data from stands representative of subalpine fir forests below the whitebark pine zone (Cooke City, MT, subalpine fir with occasional and seral whitebark pine), whitebark pine woodland (Kings Hill, MT), krummholz (Old Glory Mountain, BC), and alpine tundra (Niwot Ridge, CO) above the range of the tree are compared in figures 1 and 2.

Data comparing the climates of *Pinus albicaulis* (whitebark pine), *Pinus cembra*, *Pinus sibirica*, and *Pinus pumila* appear in table 2.

THE CLIMATE OF WHITEBARK PINE WOODLANDS

The climate of woodlands where whitebark pine dominates (latitude 37° to 47° N.) is interpolated from data gathered in the Sierra (Ellery Lake, CA), the Cascades (Crater Lake, OR), and the Rocky Mountains (Kings Hill, MT). I summarize the data from all three stands with a description (following paragraph) organized around the passage of seasons in a whitebark pine woodland; please refer to table 1 to develop a feeling for regional variation in the woodland climate.

The average January day warms from a nightly low of –11 °C (–14 to –8 °C) to a high of –1 °C (–3 to 1 °C). The snow pack maximizes at 1 to 3 m in February to April and shields roots, decomposers, and small animals from hard frosts. Melt-out proceeds rapidly in May, when swelling buds and newly exposed organisms may experience frosts as cold as –10 to –19 °C. While the average July day warms from a low of 4 °C (3 to 5 °C) to a high of 21 °C (19 to 22 °C), the probability of a frost (0 °C) is still about 7 percent. Because the coarse soils of whitebark pine sites are usually more than saturated by snow melting in May to June, large differences in winter snowpack between sites or seasons are dissipated by runoff and probably go unexpressed in summer production. Production above a minimum set by the site's soil water holding capacity may be supported by July to September rains whose total deposits range from 25 mm to 180 mm (average 92 mm). The rain is deposited in five to 11 monthly showers, of which over half are so small (less than 2.5 mm) that they are probably useful only to insects and nonvascular plants (Weaver 1985). While snow showers occur in September and October, snow does not accumulate permanently until near the first of November.

CHANGES IN CLIMATE ACROSS THE WHITEBARK PINE ZONE

In the Northern Rocky Mountains, USA, whitebark pine is absent from foothill grasslands, Douglas-fir (*Pseudotsuga menziesii*) forests, and the lower part of a subalpine zone largely dominated by fir (*Abies lasiocarpa* at climax) and pine (*P. contorta* at subclimax). The species appears as an occasional and seral tree in the upper half of the subalpine zone, dominates woodlands just below timberline, is often important in krummholz, and is absent again in the alpine tundra. One would ideally describe changes in climate along this altitudinal-vegetational gradient by summarizing data from weather stations arranged along two to three geographically well-separated transects across the gradient (Marr 1961; Price and Evans 1937). In the absence of such data, changes in climate across the gradient are demonstrated on a synthetic gradient, that is, with graphs comparing, one by

Table 1—Climate[1] of high-altitude environmental types of the western United States

	Environmental type and location[2]								
	High-elevation fir		WB woodland			WB timberline		Alpine	
	Lake WY	Cooke MT	Ellery CA	Crater OR	Kings MT	Glory BC	Sunshine AB	Niwot CO	White CA
Temperature (°C)									
Abs. minimum	–44	–39	–32	–29	–38	–38		–38	–37
Abs. May min	–19	–16	–19	–13	–10	–13		–26	–17
Jan. mean min	–18	–16	–13	– 8	–14	–12	–21	–17	–12
Jan. mean max	–5	–6	1	1	–3	–7	–15	–10	– 5
July mean min	4	3	3	4	5	6	1	4	2
July mean max	22	23	19	20	22	14	17	12	12
Abs. max	33	29	26	32	31	27	30	21	20
July frost days	4	3	6	4	2	3		1	6
Precipitation[3] (mm)									
Mean annual	559	672	604	1,611	755	757		1,059	497
July–Sept.	130	159	68	89	120	130		137	86
Driest summer month	7	9	0	0	15	1		1	0
Wettest summer month	127	118	87	136	90	150		95	114
Summer shrs >0.02	11	11	5	6	11	10	10	11	4
Summer shrs >2.54	6	7	2	4	7	5	5	6	2
Snow[4]									
Months >0 cm		7		8	7	7			7
>30 cm		4		6	6	5			5
>50 cm		4		6	4	5			4
Mean max (cm)		102F		290M	135M	173A			81M
Location									
Latitude (°N)	44	45	37	42	46	49	51	40	37
Longitude (°W)	110	109	119	122	110	119	115	105	118
Altitude (ft)	7,700	7,553	9,545	6,475	7,300	7,700	7,042	12,165	12,470
(m)	2,369	2,324	2,937	1,992	2,246	2,369	2,167	3,743	3,837
Decade	61-70	70-79	71-80	61-70	51-60	61-70	1978	71-80	61-70

[1]Climatic descriptions are based on a decade specified near the bottom of the table; standard error of the means would be smaller and extremes larger if a longer period had been used. Because summer data from Sunshine are available for 1978 only, only 1978 data are reported.

[2]Stations are Yellowstone Lake, WY, Cooke City, MT, Ellery Lake, CA, and White Mountain I, CA, Crater Lake, OR, King's Hill, MT, Old Glory Mountain, BC, Sunshine-Banff, AB, Niwot, CO, and White Mountain II, CA. Because no temperature data were recorded at Ellery Lake, temperature data were taken from a White Mountain Station with a similar latitude (37), longitude (108), and altitude (3,123 m).

[3]Precipitation (mm) is reported for the entire year, the dry season (July to September), the driest summer month in the decade, and the wettest summer month in the decade. The average number of showers (>2.5 mm = 0.1 inch and >0.025 mm = 0.01 inch) is reported for the June to September period.

[4]The duration of snow pack greater than 0 cm, 30 cm, and 50 cm is reported along with the maximum depth reported and its month (February, March, April).

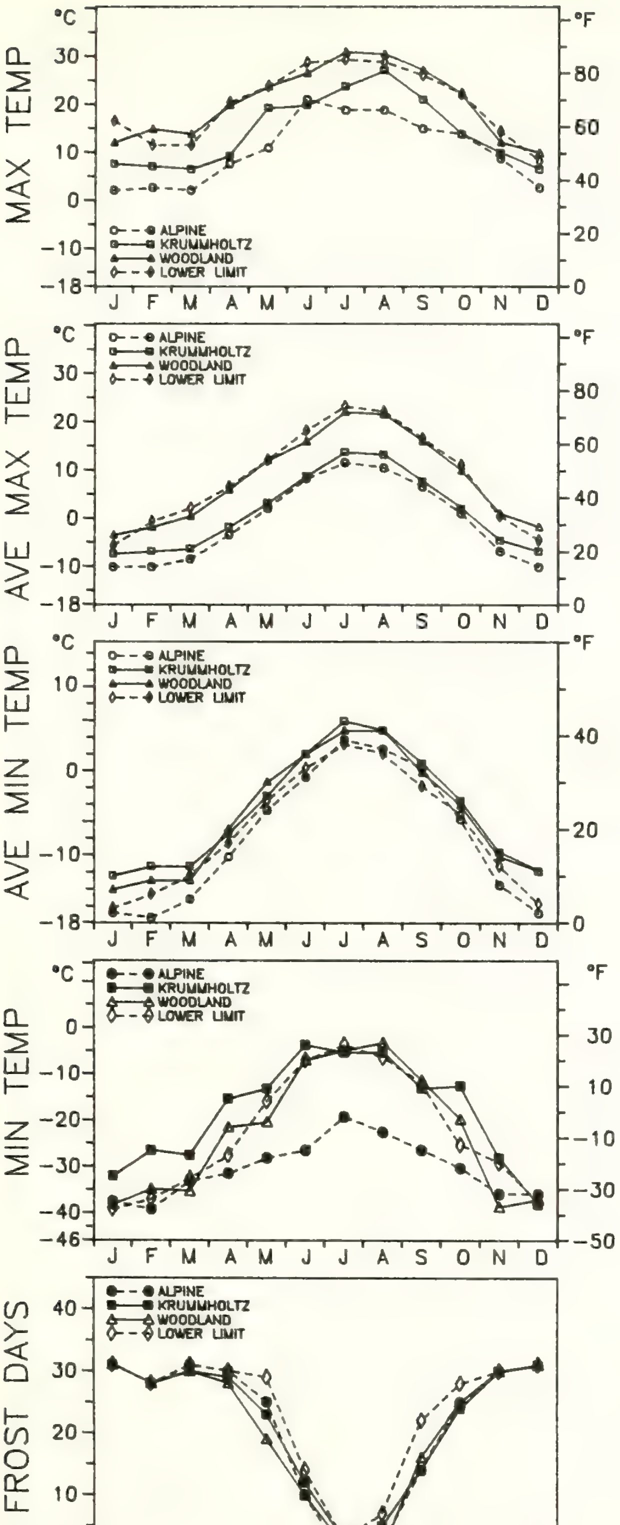

Figure 1—Comparison of temperature data from tundra, timberline, woodland, and high subalpine forests. Monthly data are summarized over a 10-year period and plotted against time. The data plotted come from the Niwot Ridge, Old Glory Mountain, King's Hill, and Cooke City weather stations; data from other comparable stations appear in table 1.

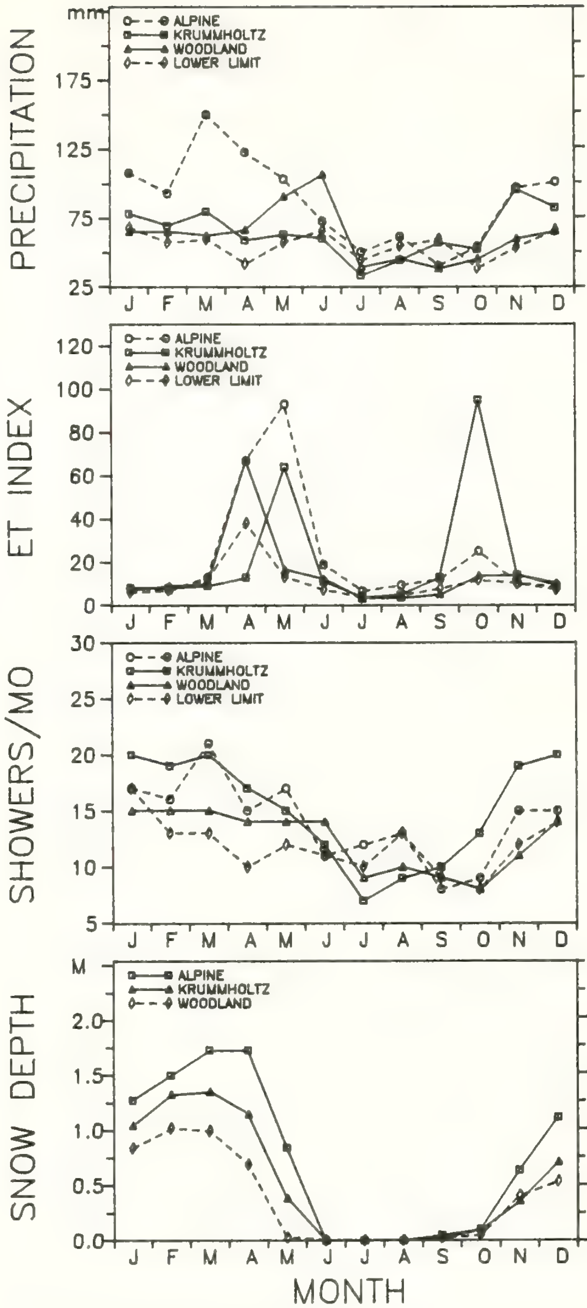

Figure 2—Comparison of precipitation data from tundra, timberline, woodland, and high subalpine forests. Monthly data are summarized over a 10-year period and plotted against time. A P/T index value of 1 indicates a relatively droughty season (Daubenmire 1956; Walter and others 1975); no alpine point falls below 5; timberline and fir types have 2 near-droughty (I = 2 to 5) months, and the woodland had 3 near-droughty months. The data plotted come from the Niwot Ridge, Old Glory Mountain, King's Hill, and Cooke City weather stations; data from other comparable stations appear in table 1.

Table 2—Climate[1] of stone pine communities of North America and Eurasia

	Species and location			
	P. albicaulis North America	*P. cembra* Euro-Alps	*P. sibirica* Siberia	*P. pumila* N. China
Temperature[2] (°C)				
Abs. min	–34 ± 2	–23 ± 1	–55 ± 2	–52 ± 4
May min	–16 ± 2	–10 ± 1	–18 ± 2	–21 ± 2
Jan. mean min	–14 ± 2	–8 ± 0	–27 ± 2	–30 ± 8
Jan. mean max	–5 ± 3	–1 ± 1	–19 ± 2	–24 ± 9
July mean min	4 ± 1	5 ± 1	12 ± 1	8 ± 0
July mean max	18 ± 1	14 ± 1	21 ± 1	15 ± 2
Abs. max	29 ± 1	27 ± 2	37 ± 1	33 ± 1
Precipitation[3] (mm)				
Total	[2]931 ± 229	939 ± 9	432 ± 21	[2]407 ± 137
Summer	102 ± 14	323 ± 36	187 ± 11	143 ± 43
Summer dry month	4 ± 4	45 ± 16	8 ± 2	4 ± 2
Summer wet month	116 ± 16	214 ± 15	181 ± 8	165 ± 25
June-Sept. showers (No.)	8 ± 1		14 ± 1	1 ± 1

[1]Values presented are mean ± one standard error. Sample size is 4 for *P. albicaulis* (except average max and mins for January and July, $n = 5$), 3 for *P. cembra*, 8 for *P. sibirica*, except for average max and mins for January and July, $n = 4$), and 8 for *P. pumila* (except for average max and mins for January and July, $n = 4$).

[2]Temperature data (°C) are the mean ± one standard error. Absolute temperatures are recorded for 10 years in *P. albicaulis* and *P. cembra*; records for the Asian pines are longer (and unspecified).

[3]Precipitation (mm) data are total (sum of all months), summer (July, August, plus September), driest summer month (July to September) recorded, wettest summer month (July to September) recorded, and average number of showers in June toSeptember. High variances in total precipitation for *P. albicaulis* and *P. pumila* are reduced to 705 ± 51 mm and 274 ± 37 mm by omission of the Crater Lake and Petropavlovsk stations, respectively.

one, the annual course of nine factors at Cooke City, MT (subalpine fir with seral whitebark), Kings Hill, MT (woodland), Old Glory Mountain, BC (treeline = upper krummholz), and Niwot, CO (alpine). The reader should refer to table 1 to become convinced that the stations presented do reasonably represent other stations in their zones and, thus, that the comparison of data from these sites accurately represents climatic changes that would occur on a gradient across a whitebark pine woodland at any single location.

In the following discussion the climates of high-altitude vegetation zones will be related primarily to whitebark pine performance. A reader wishing to relate the data to other organisms or phenomena can do so by using community characteristics (for example, seral whitebark, whitebark woodland, whitebark krummholz, or above whitebark's range) as indicators of the position of a different phenomenon (for example, performance of another organism) in the climatic gradient.

Whitebark pine is most likely excluded from low-altitude grasslands and forests by high temperatures or scarcity of water. While temperatures at lower altitudes are warmer [average July maxima are 28, 26, 25, and 20 °C in foothill grasslands, Douglas-fir forests, low subalpine fir forests, and whitebark woodlands, respectively (Weaver 1980) (table 1)], high seedling photosynthesis at temperatures as high as 30 to 35 °C (Jacobs and Weaver, this proceedings) as well as the survival of specimen trees in lawns in the foothill grassland zone argue against temperature control. Lesser precipitation [380, 580, and 755 mm in foothill grasslands, Douglas-fir forests, and whitebark woodlands (Weaver 1980 and table 1)] and longer droughts [drought indices of 1.8, 0.3, and 0.0, respectively (Weaver 1980)] probably exclude whitebark pine from the grassland and Douglas-fir zones.

It seems unlikely that whitebark pine is excluded from lower parts of the subalpine fir zone by drought, since warmer (25 versus 20 °C) and perhaps rainier (82 versus 60 to 75 mm) conditions in the lower subalpine zone compensate to produce an equally drought-free condition (0.0 month drought index, Weaver 1980). If drought stresses and substrates are, in fact, similar, it seems likely that the lower limit of whitebark pine forests is set by competition rather than by climate (Arno and Weaver, this proceedings).

We reason, from the preceding, that the lower limit of whitebark dominance is set by conditions that limit the performance of its competitors upslope. The expectation that low temperatures probably eliminate whitebark competitors from the higher subalpine woodland zone is supported by the observation that whitebark pine and spruce range farther down into cold-air pockets than do lodgepole pine or subalpine fir. Two climatic differences between whitebark woodlands and subalpine forests below them seem contrary to this expectation: average minimum temperatures are higher and frost days are fewer in the higher altitude forest (fig. 1). I believe that the conclusion suggested—that whitebark woodlands require warm nights—is spurious and that the data result from a correlation between the presence of the tree,

coincidental climatic data, and topographic-edaphic conditions which actually control locally. In the high subalpine zone the tree often grows on steep, rocky ridges from which cold air drains (yielding the warm night condition) and on which excessive drainage occurs (causing drought better tolerated by whitebark pine than subalpine fir). A scan of the other climatic data available (figs. 1 and 2) shows no differences—in either "killing factors" (absolute maximum or minimum temperatures) or factors likely to affect growth and competitiveness (average maximum temperatures, average mean temperatures, or drought months)—between the climates of climax whitebark woodlands and subjacent subalpine fir forests with whitebark subclimates.

Above the whitebark pine woodlands the tree gives way, via krummholz, to alpine tundra. The low stature of tundra vegetation makes the possibility of its competitive domination of forest trees seem unlikely. One therefore hypothesizes that one or more physical factors control tree distribution (Arno 1984; Tranquillini 1979) and looks to climatic data to clarify some possibilities. First, temperature effects. On our synthetic temperature gradient the small drop—relative to the temperature range observed within whitebark pine communities—in absolute high, average maximum, and average minimum temperatures from whitebark to alpine sites is so small that control by high or average temperatures (heat sums) seems unlikely (fig. 1). The far larger drop in absolute lows across the woodland-alpine gradient—and especially so in summer—suggests that growing season frosts could be an important factor in the final elimination of whitebark from high-altitude sites (fig. 1). This conclusion is supported by the absence of whitebark pine from the depths of frost pockets. As to mechanism, Tranquillini (1979) argued that, while early summer frosts may deform them, trees are more likely killed by winter desiccation, desiccation due to a cuticle inadequacy attributed to a short growing season. The climatic feature controlling cuticle development may be frosting (correlated with lows) rather than inadequate heat sums (correlated with averages) since opening and closing of the photosynthetic season is largely induced by frosts (Tranquillini 1979). Second, neither precipitation nor a drought index that ignores wind flow, become more unfavorable as one ascends from whitebark pine woodland to the tundra above. Third, other factors—such as high wind [contributing to desiccation through blasting and water transports (Hadley and Smith 1986; 1987)] and bleaching radiation (Tranquillini 1979)—for which we add no data, may contribute, in concert, to the disappearance of trees. Fourth, whether one factor or several acting in concert prohibit trees, the fact that timberline vegetation changes faster on the altitudinal gradient than any postulated climatic factor is nicely explained by the observation that, until the canopy begins to open, trees provide mutual shelter (Tranquillini 1979). This explanation applies to all factors from frost damage to frost-free period, degree days, wind blasting, desiccation, UV damage, or other factors considered by Tranquillini (1979) and Arno (1984).

Snow data (fig. 2) show that snow depth and duration generally increase with altitude. While the shielding of roots from hard frosts is probably important to trees, I doubt that the small differences observed control tree distribution. On the other hand, deep, long-lying snow undoubtedly benefits low organisms (for example, seedlings including those of whitebark pine, low plants, decomposers, and small animals) by shielding them from frost or predators—and may hinder them by crushing or supporting snow mold. It simultaneously affects large animals by covering their foodstuffs. Benefits and disbenefits are magnified on wind scour and wind deposit sites both above and below timberline.

Rain shower numbers in the Rockies range from 20 per month in winter to 10 per month in summer (fig. 2); summer showers are half as common on the Sierra-Cascade axis (table 1). Summer shower numbers vary little with altitude (Weaver 1985) and vary little between high-altitude types. About half of the showers at this altitude deposit less than 2.5 mm (table 1). While showers less than 5 mm may be important to mosses, lichens, and small animals ranging from insects to squirrels, their shallow penetration and rapid evaporation from both plants and soil render them largely ineffective to most vascular plants (Weaver 1985).

STONE PINE CLIMATE

Two stone pines (*Pinus sibirica* and *Pinus pumila*) dominate vast areas in northern Eurasia and two stone pines appear in high-altitude woodlands in the Alps (*Pinus cembra*) and the Rocky Mountains (*Pinus albicaulis*) (Crichfield and Little 1966). Their close relationships and ecological similarities (Mirov 1967) invite comparison of their climates as a test of the hypothesis that similar communities indicate similar climates.

While winter temperatures are especially low in stone pine communities of northern Eurasia, summer temperatures are similar in areas dominated by all four trees. Since the trees are dormant at midwinter, transplanted *Pinus albicaulis* and *Pinus cembra*, which normally experience absolute lows of only –21 to –38 °C, might tolerate the –34 to –67 °C lows experienced by their near-relatives of northern Eurasia. Frost danger is much more similar during the growing season; for example, at a hypothetical bud break in May absolute lows are all in the –10 to –21 °C range. Absolute highs are higher on Eurasian plains than in subalpine woodlands (table 2). Average maximum temperatures in July are slightly warmer in pine communities of the Eurasian plains (15 and 21 °C) than in pine communities of more southerly mountains (14 and 18 °C). Average minimum temperatures in July are also higher on the Eurasian plains (8 and 12 °C) than in subalpine woodlands (4 and 5 °C).

Although precipitation regimes differ considerably among stone pine habitats, the water regimes are apparently equivalent. In contrast to whitebark pine's winter wet/summer dry climate, all the Eurasian pines experience a winter dry/summer wet climate. In all four regions, however, snow accumulates over winter, melting snow saturates the soil, and excesses run off. Thus, wherever soil water-holding and drainage properties are similar, runoff should eliminate any effect of the large differences in October-June precipitation (603 to 829 mm for *Pinus albicaulis*, 616 mm for *Pinus cembra*, 245 mm for

Pinus sibirica, and 264 mm for *Pinus pumila*) and provide similar starting conditions. Stored soil water must provide survival water during occasional summer months in which rainfall provides as little as 0 to 13 mm, regardless of the region and community type. To the extent that moss-lichen-insect biotas are controlled by temperature and superficial moisture (numbers of June to September showers) these biota may differ little between stone pine communities.

Comparison of production data among these forests should suggest the degree to which growth—as opposed to survival—is limited by water availability. While growing season water availability differs considerably among regions (July to September precipitation for *Pinus albicaulis*, *Pinus pumila*, *Pinus sibirica*, and *Pinus cembra* is 102 mm, 143 mm, 187 mm, and 323 mm, respectively), there is probably little difference in other factors likely to control growth. Temperatures are similar (table 2). Nutrient availabilities are unlikely to differ systematically among regions so large. And underlying genetics (as suggested by taxonomic status) are similar.

I conclude that, while stone pine woodlands in one region indicate very similar climatic conditions, the degree of climatic similarity may decline with increases in the distance between the regions considered. Climatic differences increase as one compares stone pine climates in Montana with others in Montana, Oregon, and Eurasia. The climates appear, however, to be equivalent for stone pines; that is, effective growing season temperatures and water availabilities seem so similar as to permit success in transplanting. These equivalences should apply to other species with similar requirements, but they deteriorate for very different organisms: a person moving from a stone pine community in Montana to one in Eurasia will have to buy a warmer coat and a bigger umbrella. Indicator organisms are, then, good indicators of equivalencies for their near relatives, but relatively poorer indicators of conditions needed for the success of increasingly different species.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from R. Brown)—Is summer or winter desiccation more limiting to the distribution of whitebark pine?

A.—My study is correlative and therefore generates hypotheses rather than testing them. Altitudinally, I speculate that whitebark is excluded from grasslands, but not from subalpine forests and alpine tundra, by summer drought. Tranquillini (1979) argued that the upper limit of *Pinus cembra* is set by winter desiccation, possibly because of inadequate cuticle; a similar explanation for whitebark's distribution is not inconsistent with the data presented. Geographically, I speculate that whitebark's dominance declines to the north and west when more water-demanding competitors are supported, to the east when mountain sites with climates cool enough to exclude competitors or moist enough to support the tree disappear, and to the south when high-altitude sites become too dry, probably in the summer (Arno and Weaver, this proceedings).

Q. (from L. McHargue)—Is summer rainfall important to whitebark pine and, if so, would you expect especially resistant ecotypes in the summer-dry Sierra Nevada?

A.—Whitebark must maintain a minimal water content in the summer. Its dominance is greatest in summer-dry regions, and in these regions it must depend for survival water on soil water stored during the winter. Near and north of the Canadian border (Arno and Weaver, this proceedings) summer rainfall becomes more plentiful; since ecotypes (ecoclines) develop along most environmental gradients, I would expect some ecotypic variation with respect to late-season activity across the north-south range of the tree.

Q. (from M. Merigliano)—Might the near-absence of whitebark pine on interior Great Basin ranges—as opposed to the Cascade-Sierra axis—be due to the clear, sunny rather than more overcast winter days?

A.—Tranquillini suggests that upper timberline is controlled by winter desiccation. On this basis, one might expect the timberline in a region with clear, sunny winter days to be lower than that of a cloudier region. If timberline were pushed down to levels with summer warmth great enough to support competing trees, whitebark might be squeezed out.

Q. (from R. Krebill)—You have described the present climates of sites now occupied by whitebark pine. Are those climates the same as the climates the stands established in? Are whitebark stands "in sync" with today's environment?

A.—Weather varies from day to day and year to year; climate (average weather) varies from decade to decade and century to century (consider the little ice age, the hypsithermal, and the Wisconsin glaciation); and the difference between the two depends on the life span of the observer. In the Northern Rocky Mountains, I see reproduction throughout the altitudinal range of whitebark pine and I presume it exists throughout the geographic range of the species. If so, from the viewpoint of whitebark pine, the regional climate has not changed significantly and the tree is "in sync." Global warming of 1 to 5 °C, predicted by some (not all) current climatic models, may be comparable to that which occurred during the hypsithermal, and while it might not drive the tree from the region, it would surely induce a redistribution.

USING WIND-DEFORMED CONIFERS TO MEASURE WIND PATTERNS IN ALPINE TRANSITION AT GLEES

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ABSTRACT

The Glacier Lakes Ecosystem Experiments Site (GLEES) is a high-elevation ecosystem in the Snowy Range west of Laramie, WY, that is perceived to be highly sensitive to changes in chemical and physical climate. Deposition of atmospheric chemicals to this ecosystem is, in part, governed by the wind pattern. The GLEES has numerous wind-swept areas where the coniferous vegetation growth pattern is characteristically wind deformed or krummholz. Studies conducted in 1988 determined direction and degree of wind deformation of Engelmann spruce (Picea engelmannii) *and subalpine fir* (Abies lasiocarpa) *trees. Where both species occurred together, their wind deformation was similar. Limber pine* (Pinus flexilis) *occurred as scattered, isolated individuals on exposed ridges with extensive deformation, but because of its sparse occurrence was not useful in determining windspeed and direction in the GLEES. Engelmann spruce and subalpine fir tree deformation patterns were used to determine wind fields, which were compared with measured meteorological data at GLEES.*

INTRODUCTION

In recent years, forest managers have been faced with questions concerning the impact on sensitive ecosystems of atmospheric deposition of air pollutants from new or proposed point sources. Air quality legislation, written to prevent significant deterioration of present air quality in Class I or wilderness areas, requires forest managers to determine potential impact of pollutant sources on the ecosystems they manage. Alpine and subalpine wilderness ecosystems are thought to be particularly sensitive to increased atmospheric deposition. The existence of these high-elevation ecosystems is already fragile; any additional stress might have a large negative impact on their growth and survival. Few data are available to determine the potential effects of increased atmospheric deposition on such sensitive ecosystems.

A study area has been established in southeastern Wyoming to examine the effects of atmospheric deposition on alpine and subalpine ecosystems. The Glacier Lakes Ecosystem Experiments Site (GLEES) is a 200-ha alpine and subalpine watershed on the Medicine Bow National Forest, about 70 km west of Laramie, WY. The following site characteristics make it ideal for studying the effects of atmospheric deposition on wilderness ecosystems.

1. High elevation (3,400 m) typical of many western U.S. wilderness ecosystems
2. Management to preserve its natural state, but not a statutory wilderness area restricting research use
3. Exposed, slowly weathering bedrock, with shallow immature soils having low base saturation
4. Habitats similar to western wilderness ecosystems, with alpine and subalpine types dominated by spruce-fir; wind deformed spruce, fir, and willow; extensive meadow; and cushion plants
5. Low pollution impact at present, yet ecosystem is sensitive to any additional stress such as atmospheric pollutants
6. Lakes with low acid neutralizing capacity
7. Short growing seasons with cool temperatures and summer frosts
8. Deep snowpack that accumulates atmospheric pollutants
9. Complex terrain with rapid changes in topography
10. Persistent, high winds

Windspeed and wind direction are climatological components that exert major influence on alpine and subalpine ecosystems. Winds interact with terrain, producing local changes in wind direction, turbulent zones, and windspeeds over and through the surface vegetation. They determine precipitation patterns, snow distribution, snow pack accumulation, and resultant vegetation type and growth form. Atmospheric deposition will likely be greatest in areas where windspeeds are low, and turbulence is enhanced. Low windspeed allows particulates to settle. With greater turbulence, gaseous pollutants have greater potential for absorption or plant uptake, due to increased vertical mixing.

Paper presented at the Symposium on Whitebark Pine Ecosystems: Ecology and Management of a High-Mountain Resource, Bozeman, MT., March 29-31, 1989.

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Meteorological data on wind direction and speed are expensive and difficult to obtain at remote, high-elevation sites. A surrogate for wind instrumentation has been the use of asymmetric tree deformation to indicate direction and speed of prevailing wind. Direction of wind is indicated by compass direction of the deformation. Speed is calculated from empirical equations derived from actual windspeed data and amount of tree deformation in areas where both weather monitoring and tree deformation data are available.

The relationship between windspeed and deformation varies with tree species. Some species are more susceptible to deformation than others. Deformation is caused by ice crystal abrasion and desiccation of leaf bud and foliage tissue on the windward side of the tree (Holtmeier 1980). This tissue is killed, causing a slow development of surviving buds and branches on the lee side of the tree. Such selective upwind mortality leads to growth and development of branches and foliage primarily on the protected, lee side of the tree. As branch development and growth become dominant on the lee side of the tree, the tree becomes asymmetric. The degree of asymmetry or deformation is related to the speed of the wind. Season of high wind is also important, since plant tissue differs in sensitivity to wind abrasion with stage of development. Data from GLEES indicate that wind direction varies little with season. Although windspeeds are highest during the winter and spring months, winds are still strong during sensitive stages of plant growth. Measurement of amount of tree deformation also will give a long-term integrated estimate of snow depth at individual tree locations, as indicated by snow cover effects on tree growth and development.

The objectives of this study were to determine wind direction, windspeed, and snow depth in the GLEES watershed from tree deformation indices. The resulting information will be used to estimate areas of greatest impact from atmospheric deposition. Engelmann spruce (*Picea engelmannii*) and subalpine fir (*Abies lasiocarpa*) are the dominant coniferous species in the watershed. Scattered individuals of limber pine (*Pinus flexilis*) also occur. Limber pine rarely fruits in the watershed, and young trees are rare. For Engelmann spruce and subalpine fir, seedling trees are evident in the lower, subalpine portions of the watershed; but most reproduction near alpine appears to be vegetative by layering.

EXPERIMENTAL METHODS

Tree deformation indices have been developed to estimate windspeed. The Griggs-Putman technique (Robertson 1987) rates degree of deformation on a scale of 1 to 8, with 1 indicating no deformation and 8 indicating deformation such that tree growth is flattened against the ground in what is often referred to as "krummholz" form. This method uses regression techniques with constants from empirical data to calculate windspeed. The Wade-Hewson deformation ratio (Wade and Hewson 1979) measures the asymmetry of the crown and the down-wind bending of the trunk. The tree is photographed perpendicular to the maximum deformation, and analyzed using a grid overlay on the photo to measure deformation angles. Tree ring analysis can also be used to estimate windspeed (Robertson 1986). Tree sections are measured for ring width on the lee and windward side of the trunk, with ring width wider on the lee or branched side. This technique is less sensitive as an indicator of wind deformation than the others, and requires destructive sampling.

In many mountainous areas, maximum snow depth occurs early in the snow season, often as early as January (Schild and Gliott 1981), with additional snowfall settling and compacting the snowpack. Therefore, the portion of the tree exposed to wind desiccation and snow or ice crystal abrasion remains somewhat constant throughout the coldest part of the winter. This maximum depth of snowpack on trees can be measured by observed differences between snow-covered and snow-free portions of the crown resulting from the long period of exposure to their snowy or snow-free environment.

Snow depth is estimated on trees by two contrasting methods, depending on the density of the canopy. In dense canopies with deep snow, brown felt blight (*Herpotrichia juniperi*) develops on snow-covered foliage resulting in death of the needles. This is indicated by areas of dead, fungus-covered needles, or defoliated branches near the base of larger trees. The top of the dead area generally marks the maximum snow depth. The other method relates directly to wind deformation, caused by ice abrasion at the top of the snow pack (Hadley and Smith 1986; Holtmeier 1985). Beneath the snowpack, asymmetric deformation does not occur. Above the snowpack, often delineated by a sharp line of a few centimeters, tree deformation becomes evident. This indicator of snow depth is much more distinct than the snow mold technique, but is not useful in dense canopies where wind abrasion and deformation may occur only in the tops of the tree crowns. Some evidence of the depth of the snowpack is also indicated by the bending of branches downward from the weight and settling of the snowpack; but subalpine conifers are remarkably resilient in resisting this type of damage.

For this study, the GLEES was divided into 100-meter grid mapping units, with a tree sampled for deformation near each grid intersection. Individual trees near each grid point, considered typical of that area in amount of deformation, were selected as sample points. This scale of sampling was considered adequate to identify areas of different atmospheric deposition potential within the watershed. Individual trees sampled were identified on aerial photos for precise location of windspeed and direction data within the watershed. Wind direction was determined by measuring compass direction of the primary orientation of asymmetry or bending. Windspeed was

calculated using both the Griggs-Putman and Wade-Hewson index methods described above. Snow depth was estimated from tree deformation markers at the lower portion of the tree trunk.

RESULTS AND DISCUSSION

Results of the study indicated that tree deformation indices for Engelmann spruce and subalpine fir were useful for estimating wind direction, windspeed, and snow depth at the GLEES. Wind direction was consistent, generally from a westerly direction at all sites within the watershed. The wind direction indices reflected local patterns of topography, with wind generally following parallel to a steep ridge bordering the watershed, but with some minor channeling around smaller ridges and knolls. Some convergence was evident in a small valley, and slight divergence of flow was evident where it passed over a ridge line as it exited the watershed.

The windspeed calculations for both the Griggs-Putnam and Wade-Hewson index methods provided similar windspeed values for individual trees. Because of their similarity, an average of the two methods was used as the estimate of windspeed at each data point in the watershed. The windspeed data, derived from individual trees based on their deformation indices, varied from 3 to 11 m/sec at different sites throughout the watershed, with an average watershed windspeed of 7.4 m/sec. The data derived from tree deformation indices are consistent with limited (1-year) data from a meteorological tower located within the watershed. The meteorological tower data indicate an average windspeed of 9.4 m/sec at that particular site. Tree deformation at a grid point located 20 m southeast of the tower indicated an identical windspeed of 9.4 m/sec. This degree of accuracy is perhaps coincidental, but demonstrates the usefulness of tree deformation as a surrogate for meteorological instrumentation.

The snow depth estimations from height of fungal injury and initiation of tree deformation indicated that snow depth varied from less than 0.5 m to over 4.5 m within the watershed. The average snow depth within the watershed estimated from tree indices in this study was 1.9 m. Precipitation data recorded from a raingauge located within the watershed from 1979 to 1988 have indicated an average maximum seasonal snowfall of about 2.1 m. This estimate is based on a 20-percent adjustment for observed collection inefficiency of raingauges located in windy sites (Sommerfeld and others in preparation). This correction may be low, particularly for snowfall at high wind sites (Sturges 1986). It also does not account for snowpack settling. On the other hand, the tree deformation index of snow depth is also likely low, since trees would be deformed to the lowest point on the trunk during low snowfall years. The techniques used for identifying snow depth on trees in this study would indicate this minimum height of snow accumulation on the tree trunk.

Engelmann spruce and subalpine fir tree species were useful to estimate wind direction, windspeed, and snow depth. These species occurred at sufficient frequency to allow adequate coverage of all areas of the watershed except the highest elevation alpine meadows, talus slopes, and snowfields. These treeless areas, on the lee side of the large ridge bordering the watershed, accumulate large amounts of snow and appear to experience high windspeeds. Tree deformation indices indicated increases in windspeed moving upslope toward these areas.

Engelmann spruce occurred most frequently in the lower subalpine portions of the watershed. However, the species did occasionally occur as krummholz at the higher elevations. Subalpine fir was most abundant in the upper portions of the watershed near alpine, where it was extensively wind deformed as krummholz. Individuals of subalpine fir also occasionally occurred at the lower elevations. Where both species occurred together, no difference was noted in the degree of wind deformation. At higher elevations, both species formed ribbons and hedges (Holtmeier 1978, 1980, 1982), wave patterns typical of high-wind areas in the Rocky Mountains. Engelmann spruce and subalpine fir krummholz forms were indistinguishable at a distance.

Limber pine deformation was not useful for determining wind and snow depth parameters in the watershed. Limber pine did not occur in lower elevation or protected areas where subalpine fir and Engelmann spruce were more abundant and less wind deformed. Limber pine was found primarily as widely scattered, isolated individual mature trees on ridgetop sites. Occasionally, it occurred as isolated, scattered individuals in the higher elevation areas of the extensive krummholz mats of Engelmann spruce or subalpine fir. Although almost always wind deformed at the exposed sites where it occurred, its scattered distribution prevented observations sufficient to determine wind direction and speed throughout the watershed. Since no rooting of the species was evident, extensive mat or wave patterns typical of Engelmann spruce and subalpine fir did not occur with limber pine. The inability of limber pine to reproduce vegetatively by layering likely contributed to its limited distribution in the watershed.

On the exposed sites where limber pine did occur, it was often extensively wind deformed; windspeed, direction, and snow depth could be determined from those individual trees. In areas where it might occur in denser, more widespread stands, it may be useful to estimate windspeed and direction. However, since it did not occur in more protected areas of the GLEES, sensitivity of the species to deformation at lower windspeeds could not be determined. At a few exposed sites at the GLEES, limber pine, Engelmann spruce, and subalpine fir occurred together. At these high-wind sites, limber pine appeared to indicate wind deformation patterns similar to those of the spruce and fir.

Limber pine and whitebark pine (*Pinus albicaulis*) are closely related species that occur in similar habitats. It is expected that whitebark pine would respond similarly to limber pine in susceptibility to wind deformation. Whitebark pine has been documented to occur in krummholz form (Arno and Hoff 1989; Tomback 1986). Although

rooting of krummholz whitebark pine by layering can occasionally occur (Arno and Hoff 1989), vegetative reproduction of the species in krummholz is rare. Reproduction of the species is predominately from seed transported to timberline sites by birds (Tomback 1986). Local seed production in krummholz stands is low, and seeds produced have lower germination capacity than nonkrummholz stands (Tomback 1986). Scavenging of seed cones by birds and mammals is high in these sites (Tomback 1986). Thus the distribution of whitebark pine in sites subject to wind deformation is limited compared to distribution of Engelmann spruce and subalpine fir, which readily spread in krummholz stands by layering.

As with limber pine, only where whitebark pine occurs at least as densely as that required here (100-m or smaller grid) would it be useful as a surrogate to determine windspeed and wind direction data in a watershed. Another closely related species, European stone pine (*Pinus cembra*), grows in similar habitats and is commonly wind deformed. This species has been used to relate deformation to windspeed and direction in mountainous terrain (Holtmeier 1985).

The 100-m grid was sufficient to delineate wind direction, which changed little throughout the watershed, and proved adequate for windspeed. Refinement of windspeed would have been possible with survey at a closer grid pattern. The snow depth determinations appeared to be the least precise. Snow depth varied on a very small micro-relief scale, and changed with the particular tree chosen for sampling. Amount of tree deformation and direction changed little at a given site. This suggests that more precise snow depth delineation might have been possible from sampling at a finer scale of resolution. We were, however, able to refine the precision of the snow depth measurements for the watershed using a series of aerial photos of snow fields during melt to determine where areas of adjacent, similar snow depth might occur. In such cases, care was taken not to compromise the integrity of the snow depth data from tree deformation indices. For example, aerial photographs suggested that isopleths of particular snow depths may have closed in certain areas where they might have been drawn parallel.

The snow depth estimates from tree indicators provided data that generally corresponded with topographic features, such as lower snow depth on windswept ridges, and greater depth in the lee of ridges, where upslope conditions prevailed, and on the windward side of large open areas such as lake surfaces. However, a regression of windspeed on snow depth/tree as indicated by tree deformation indices was not significant. This was likely due to the lack of precision by tree indicators of snow depth, and the sensitivity of snow depth to small changes in topography. Maps showing wind direction, windspeed, and snow depth within the watershed are being published elsewhere (Wooldridge and others in preparation).

This study has demonstrated the usefulness of tree deformation indices to estimate wind direction, windspeed, and snow depth in situations where meteorological instrumentation is not available or too costly to obtain such data. Engelmann spruce and subalpine fir were useful tree species to indicate these parameters at the GLEES, a small alpine, subalpine ecosystem in southeastern Wyoming sensitive to atmospheric deposition. The data obtained in this experiment will be useful for determining areas of maximum atmospheric deposition in the watershed, and will be useful in modeling water and chemical transport through the different subcatchments of this ecosystem.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from Richard Baker and Earle F. Layser)—Your preconference paper title and abstract mentioned whitebark pine, while your paper and talk referred to limber pine. Isn't the Snowy Range outside the range of whitebark pine?

A.—The species that occurs at our study site in the Snowy Range has few individuals; these rarely produce cones. No seedlings appear to be present at the site. No cone fragments were visible under the trees. We were able to locate three cones that closely resembled those of whitebark pine. When the preconference abstract was written, we had tentatively identified the species as *Pinus albicaulis* based upon these cone characteristics. However, further examination of the specimens, and considering the small number of cone samples and the location of the trees outside the range of *Pinus albicaulis* and within the range of *Pinus flexilis*, we identified the species in the paper and in the presentation as *Pinus flexilis*.

Q. (from Friedrich-Karl Holtmeier)—Did your different tree species respond in the same way to different windspeeds; do they really display the same growth form at a similar windspeed?

A.—Engelmann spruce and subalpine fir response to wind deformation at specific locations was remarkably similar. Where both tree species occurred at the same site, tree deformation indices were the same. We could not distinguish between the two species based upon tree deformation. Limber pine appeared to respond similarly to the other two species at the few sites where it occurred with Engelmann spruce and/or subalpine fir. However, these sites were located on ridgetops where windspeeds and subsequent deformation were always higher (6-8 on the Griggs-Putnam scale). Response of limber pine at the lower windspeeds is not known. Because of the sparse occurrence of limber pine, it was not used to determine wind direction, windspeed, or snow depth in this study.

Q. (from Wendel Hann)—How do the wind/ice abraided stems of whitebark grow to the size they get before they are wind damaged? For example, why doesn't the wind take the buds off and keep them low in height?

A.—Evidence suggests that the most wind desiccation and ice abrasion damage to conifer foliage occurs in a very small zone above the snow surface. If the tops of trees are able to survive a few seasons to reach beyond this level, then the probability of survival increases. Survival during this period of time is determined by a season or two of (1) mild winters where ice abrasion and desiccation are less severe; or (2) abnormally deep snowpack where the tops are protected by snowcover. The tree top may survive once it grows beyond the few centimeters at the surface of the snowpack where conditions are most severe. However, deformation still occurs, primarily from desiccation on the windward side of the stem.

AUTECOLOGY OF WHITEBARK PINE

Ward W. McCaughey
Wyman C. Schmidt

ABSTRACT

*Whitebark pine (*Pinus albicaulis*) is an unusual species with limited information available on its basic biology. This paper consolidates information on the autecology of whitebark pine, including mechanisms of flowering and fruiting, cone production, seed characteristics and dissemination, regeneration, vegetative reproduction, growth and morphology, rooting, shade tolerance, longevity, and phenology. General habitat requirements are addressed in terms of climate, soils, elevation and topography, and plant associates. The distributional range of whitebark pine is discussed along with specifics on its physical characteristics and habitat requirements.*

INTRODUCTION

Whitebark pine (*Pinus albicaulis* Engelm.) was first described by botanists in the mid 1800's and classified by Engelmann in 1863 (Bailey 1975; Engelmann 1863). Its seeds have been found to be an important food source for grizzly (*Ursus arctos horribilis*), black bears (*Ursus americanus*) (Craighead and others 1982; Kendall 1983), birds (Tomback 1982; Vander Wall and Hutchins 1983), red squirrels (*Tamiasciurus hudsonicus*), and small mammals (Hutchins and Lanner 1982). Whitebark pine is also considered valuable for watershed protection, wildlife cover, ornamental use, and esthetics. It has minor significance as a timber producing species.

Whitebark pine grows in high-elevation forests and at timberline in western North America. In some areas such as Montana, Idaho, and western Wyoming whitebark forests occupy up to 10-15 percent of the forest cover (Arno 1986). Research on whitebark pine has been minimal but interest in this species is growing.

Autecological information is limited for whitebark pine. This paper describes the distribution of whitebark along with the climate where it grows, the soils it grows on, its reproductive cycle, growth characteristics, light requirements, insect and disease problems, and plant associates.

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DISTRIBUTION

Whitebark pine grows from northern British Columbia to south-central California and from the Pacific coastal range to the Wind River range in Wyoming (fig. 1). There are two major distributions in western North America, a western and an eastern population (Critchfield and Little 1966).

The western population extends from about latitude 55° N. along the lower Fraser River in western British Columbia, southward into the Cascades, through Washington and Oregon, and on into the Sierras in California. In northern California the distribution is less continuous but farther south in the Sierra Nevada of central California it again becomes continuous forming extensive stands at and below tree line. The southern limit of whitebark is in the region of Mount Whitney between latitude 36° and 37° N.

The eastern population of whitebark pine extends southward from near latitude 55° N. in British Columbia and follows the principal ranges of the northern Rocky Mountains (Critchfield and Little 1966). Whitebark is found in the higher mountains of western Montana and central Idaho and extensively in the Yellowstone region of south-central Montana and northwestern Wyoming. The Wind River range of western Wyoming represents the southern and eastern limit of the eastern population of whitebark except for some disjunct stands in northeastern Nevada.

The eastern and western populations are separate except for a connection by isolated stands in southern British Columbia and northeastern Washington. Between the two distributions whitebark occurs in the Blue and Wallowa Mountains of northeastern Oregon and in small isolated ranges in northeastern California, south-central Oregon, and northern Nevada (Arno and Hoff 1989). There are also outlier stands of the eastern population in the Big Horn and Wind River ranges of Wyoming and in the Sweetgrass Hills in Montana (Thompson and Kuijt 1976).

The distribution of whitebark pine can be divided between Canada and the United States. In most of its distribution in Canada, whitebark north of latitude 50° N. is a minor component of the high-elevation forests (fig. 1). In the United States, whitebark often is a major component in the subalpine forests, sometimes forming pure stands.

Whitebark pine is a timberline tree found on the highest summits throughout its range. It grows at elevations of 6,000 to 7,000 ft toward its northern limits, from 5,500 to 9,300 ft in Oregon, 7,000 to 11,000 ft in California, and at 5,000 to 10,000 ft in Idaho and Montana (Sudworth 1908).

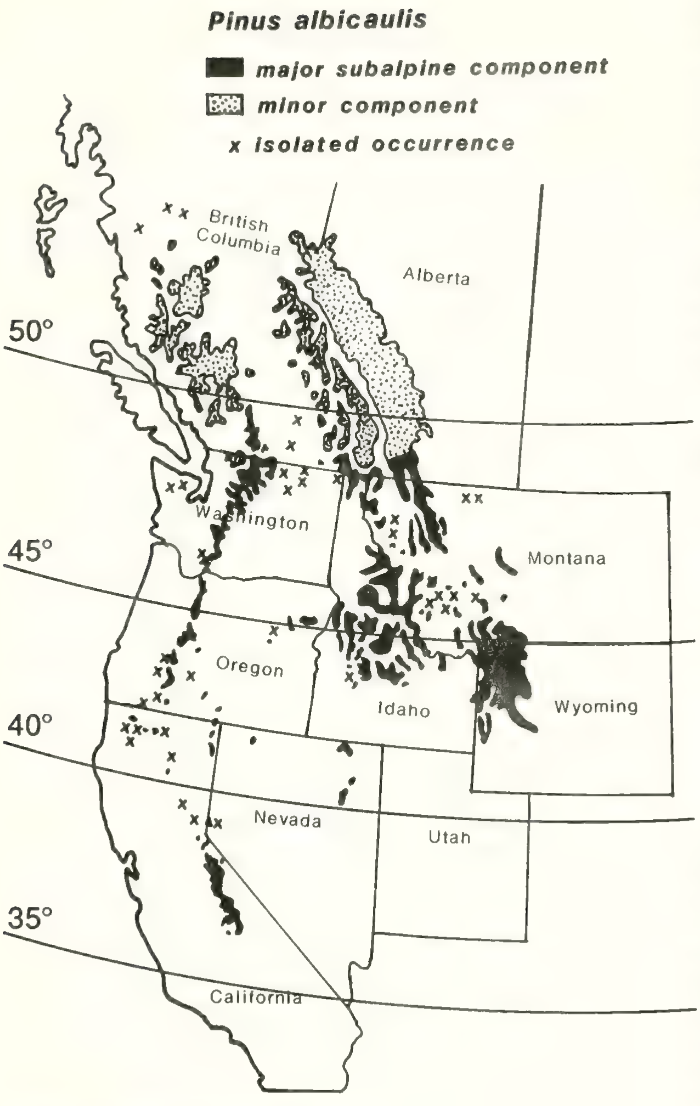

Figure 1—Distribution of whitebark pine.

CLIMATE

Whitebark pine grows from high-elevation alpine to montane forest sites at its lower elevational limits. It is most abundant on warm-dry exposures in moist mountain ranges and is prevalent on cool-moist sites in semi-arid ranges (Arno and Hoff 1989). At whitebark's upper elevational limits, it grows under extreme seasonal changes with daily temperatures ranging from lows near –60 °F in winter to over 100 °F in summer (Sudworth 1908). Summer temperatures are cool with July temperatures ranging from 55 to 59 °F in pure whitebark stands and from 50 to 54 °F in adjacent timberline zones (Weaver and Dale 1974). Average temperatures exceed 32 °F in the months between May and October yet frosts can occur in any month. The average frost free season was 32 days for whitebark stands near Kings Hill in the Little Belt Mountains of eastern Montana (Weaver and Dale 1974).

Heavy snowfall, fierce winds, and a short growing season are characteristics of whitebark pine habitats. Wind gusts can exceed 73 mph on most sites, especially on ridgetops (Arno and Hoff 1989). Most precipitation comes in the form of snow anytime from October to May, although snow can occur in any month in the higher elevation stands. Rain is the prevalent form of precipitation from June through September with intense afternoon thundershowers periodically providing small amounts of moisture (Arno 1970).

In the northern latitudes, mean annual precipitation ranges between 24 and 71 inches in stands where whitebark is a major component. Rainfall is minimal in the southern portion of whitebark's distribution south of latitude 47° N. causing a droughty period during mid-to-late summer (Arno and Hoff 1989).

SOILS

Mountain soils are characterized by young soils such as entisols and inceptisols that have minimal horizon development from weathering. Pure whitebark pine stands typically occur on young inceptisol soils characterized by weakly differentiated horizons (USDA 1975). Entisols also have developed on high benches and rolling ridgetops where sand and gravel have accumulated (McCaughey 1988). These are the youngest soils with almost no horizon development. They have developed since the Pleistocene glacial period less than 12,000 years ago (Mehringer and others 1977). Because of their short period of development, inceptisol soils, such as Typic Cryochrepts, are fragmental with only minimal horizon development.

Where whitebark pine forms climax communities, it is often found on soils composed of coarse talus, exposed bedrock, or lava flows (Arno and Hoff 1989). These soils sometimes have scattered pockets of fine material that may support other conifer species such as subalpine fir. Climax stands may also occur on mollic soils (Pfister and others 1977) or on other better developed soils where the limiting factor preventing other conifers is short-cool growing season or inadequate moisture. Volcanic ash deposits in some areas develop into Andic Cryochrepts or Typic Cryandepts that support the more productive spruce-fir-whitebark stands (Arno and Hoff 1989).

A short, cool growing season is typical of the whitebark pine ecosystem. Soil temperature regimes within the whitebark zone are considered cryic, having a mean annual temperature higher than 32 but lower than 47 °F. Productivity is low in most high-elevation whitebark pine stands. Cool temperatures reduce chemical weathering and activity by nitrogen-fixing and other microbiotic organisms thus tying up most of the nutrients in the form of litter and debris on the forest floor. Weaver and Dale (1974) found that compared to Montana agricultural soils, whitebark soils were low in potassium, calcium, magnesium, and sodium, but high in phosphorus. Like most forest soils, whitebark sites are acidic with upper horizon pH values ranging from 4.7 to 6.0 in Montana and 7.8 to 8.0 in Alberta (Arno and Hoff 1989; McCaughey 1988).

Whitebark prefers non-calcareous soils but can be found on limestone soils in Montana (Pfister and others 1977; Weaver and Dale 1974). In Canada whitebark grows on limestone substrates (Weaver 1989).

PHYSICAL CHARACTERISTICS

Needles

Whitebark pine is a five-needled pine. Bud burst occurs around mid-June and needles complete their growth by early July (Schmidt and Lotan 1980). Whitebark pine has five needles per fascicle. Individual needles are three sided; the outer side is convex, the inner sides are flat. When the inner flat surfaces of the five needles fit together the fascicle forms a (rod) circle in cross-section. Needles of whitebark are $1^1/_3$ to $2^3/_4$ inches long, yellow-green in color, and have one to four light colored stomatal lines on each of the flat surfaces (Harlow and others 1979; Hitchcock and others 1969).

When cones are absent whitebark pine is very difficult to distinguish from limber pine (*Pinus flexilis* James). Limber pine needles are about $2^1/_2$ inches long and similar in structure and color to whitebark. Cell wall thickness in the needle endodermis can be used to distinguish between whitebark and limber pine. In whitebark the outer tangential walls of the endodermis are thicker than the other cell walls; those of limber pine are of uniform thickness all the way around the cell (Harlow 1931). Examination of the number of needle resin ducts can be used for quick field comparison between whitebark and limber pine, although this procedure is less reliable (Ericson 1964; Hendrickson and Lotan 1971).

Bark

The bark of whitebark pine is thin with a conspicuous chalky-white cortical appearance (Bailey 1975; Hitchcock and others 1969). The smooth or superficially scaly bark is rarely more than one half inch thick and is brownish white to creamy white on immature trees (Harlow and others 1979). The bark is rarely broken, even on older trees, except near the base. The lower bark is divided by narrow cracks creating very thin whitish or brownish scales that, after falling or breaking off, reveal a red brown inner bark (Sudworth 1908). Young twigs are pubescent while older twigs have smooth bark (Hitchcock and others 1969). The bark slips around the end of May and sticks, after summer growth, around mid-September (Schmidt and Lotan 1980).

Branches

Young trees have regular whorls of branches at right angles to the trunk, but in older trees upper whorls develop upward into long willowy stems. Branches are tough and flexible (Sudworth 1908).

Roots

Root length varies depending on the growth substrate and age of the tree. Whitebark pine germinants have a 2- to 7-inch tap root with several lateral and fine root hairs (Day 1967; McCaughey 1988). Older whitebark develop a characteristic deep and spreading root system. On glacial moraines in Wyoming, whitebark pine forms a pancake-like root system only 16 inches deep (Lanner 1981). This shallow rooting also occurs in high-elevation bogs (Arno and Hoff 1989).

Wood

Whitebark pine wood is soft, fine textured, and brittle with a light brown-colored heartwood. It is easy to saw, having a specific gravity ranging from 0.35 to 0.53, slightly heavier than subalpine fir and lodgepole pine (Day 1967; Keenan and others 1970). Whitebark pine is weaker than lodgepole pine except for compression perpendicular to grain and hardness (table 1).

Whitebark pine contains substantial amounts of solvent-extractable fractions (oils), polyphenol, and other byproducts that can be used for fuels, chemicals, and other industrial raw materials. Whitebark yields 10.1 percent oil and 19.6 percent polyphenol as well as turpentines and rosins (Carr and others 1986; Mirov 1967).

Tree Form

At timberline whitebark pine forms "krummholz" stands of shrublike trees. On more exposed sites whitebark is found as low cushion krummholz or with long prostrate, often twisted branches growing over rocks (Dallimore and Jackson 1948). This shrub form is caused by inadequate growing season length and warmth, preventing adequate growth, maturation, and minimal cuticular development of new shoots (Daubenmire 1954; Tranquillini 1979). The incompletely developed tissues allow excessive winter damage and tissue death resulting in the delimitation of upper timberline (Sowell and others 1982). Other factors that help create tree deformities of timberline trees are frost, ultraviolet and high intensity radiation, heat, wind, and snow blast damage (Baig 1972; Tranquillini 1979).

Below the krummholz zone whitebark grows in nearly pure stands of widely spaced trees with diffuse crowns. In these stands, whitebark grows from 30 to 90 ft tall and is often multistemmed (Arno and Hoff 1989; Eggers 1985; Weaver and Dale 1974). The multistemmed appearance is due in part to caching habits of the Clark's nutcracker

Table 1—Strength properties of whitebark pine at 12 percent moisture content (from Keenan and others 1970)

Strength property	Strength value
Static bending	
Modulus of rupture (psi)	8,340
Modulus of elasticity (psi)	1.20×10^6
Compression parallel to grain	5,244
Maximum crushing strength (psi)	702
Hardness	
Side (lb)	516
End (lb)	680
Shear parallel to grain (psi)	705
Tension perpendicular to grain (psi)	421
Cleavage (lb per inch width, length 3 inches)	213

(*Nucifraga columbiana*) and to natural branching habits of young whitebark (Lanner 1980; Lanner and Vander Wall 1980; Linhart and Tomback 1985; Tomback and Kramer 1980; Weaver 1989).

Whitebark has a tree form similar to lodgepole pine when grown in close competition with other species (Keenan and others 1970). Along the east slope of the Continental Divide, in northern Montana, height growth and bole diameters were identical for lodgepole pine and whitebark and from a distance it was hard to distinguish between them (McCaughey 1987). In these mixed stands, whitebark has multiple tops with forking occurring near the top of the tree.

REPRODUCTION

Flowering and Fruiting

Flowering occurs after the juvenile period, which varies greatly among conifers. The age at which flowering occurs for whitebark pine is around 20-30 years (Day 1967; Rehder 1940).

In conifers the reproductive flowers consist of pollen (staminate strobili) and seed (ovulate strobili) cones (Kramer and Kozlowski 1979). Whitebark pine is monoecious, containing both cone types on the same tree.

Whitebark pine has a 2-year flowering cycle. Initiation of flower and vegetative buds occurs during bud set in August (Allen 1941; Schmidt and Lotan 1980). Ovulate cones are sessile, occurring in clusters of two to five near the tip of upper crown branches. The staminate cones are distributed throughout the crown but most frequently on older branches in the lower crown on the current year's growth (Arno and Hoff 1989; Eggers 1985). The staminate cones are crimson red and ovulate cones dark purple. Limber pine by contrast has yellow staminate cones and green ovulate cones.

During their first full growing season staminate and ovulate cones of whitebark pine grow to a length of one-fourth inch and 1 inch respectively (McCaughey 1988). Ovulate cones are receptive to pollen when it is wind disseminated in mid-July, although this receptive period may be earlier at lower elevations (Arno and Hoff 1989; Schmidt and Lotan 1980). After pollination of ovulate cones, staminate cones fall off the tree while ovulate cones remain in place.

Growth of pollinated ovulate cones begins in June of the second summer following initiation of flower buds and continues until cones reach full size (1½ to 3½ inches) by early August (Arno and Hoff 1989; Kozlowski 1971; Schmidt and Lotan 1980). Seed continues to mature until mid-September or early October. Ripe cones are ovoid, dull purple to brown in color, resinous with thickened apophyses, have terminally armed umbos, and weigh roughly 1 to 2 oz (Harlow and others 1979; Krugman and Jenkinson 1974; Weaver and Forcella 1986).

Cone Production

Minimum seed bearing age is 20 to 30 years for whitebark pine with the interval between large crops being 3 to 5 years (Krugman and Jenkinson 1974). Throughout the Yellowstone ecosystem there were two moderate to heavy cone crops from 1980 to 1987 with overall cone production decreasing steadily during the 8-year period (Knight and others 1987). Declines in cone production in the Yellowstone ecosystem were attributed to mortality of whitebark pine trees due to the mountain pine beetle (*Dendroctonus ponderosae* Hopkins) (Knight and others 1987). On the eastern slopes of the Sierra Nevada, Tomback (1978) observed moderate to heavy whitebark pine cone crops in 4 consecutive years from 1973 to 1976. Weaver and Forcella (1986) estimated an average of 1.17 cones/yd^2/yr over a 6-to-8 year period on 28 whitebark stands in Montana. Cone yields varied significantly between years within stands and generally high-yield years followed low-yield years.

Poor cone crops may be a function of weather-related factors rather than within-tree factors (Weaver and Forcella 1986). Temperature and precipitation have significant, but not dominant, effects on all stages of cone development throughout most of the year. Allen (1941) identified several factors responsible for poor cone crops in conifers: adverse weather conditions, insect damage, and abortions that may have been physiological.

Seed Characteristics

A whitebark pine cone contains about 75 wingless seeds each weighing approximately 0.005 oz. Seeds are light brown to light orange in color, and are around 0.3 inches long. There are between 2,200 to 4,500 seeds per pound (Krugman and Jenkinson 1974; McCaughey 1988). The large variation in the number of seeds per pound is due to differences in seed size and also may be due to seed maturity when harvested.

Seed Dissemination

Whitebark pine cones have cone scales that partly open exposing the wingless seeds (Eggers 1985; Hutchins and Lanner 1982; Lanner 1982; Tomback 1981). There has been no documented evidence that whitebark pine cones abscise and fall to the ground. If cones do fall as a result of being dislodged due to animal foraging, they disintegrate rapidly by decay and depredations by animals (Arno and Hoff 1989). Groups of whitebark pine germinants were observed around crumbled cones in southwestern Alberta (Day 1967).

When cones are protected from animal predation they remain attached (Hutchins and Lanner 1982; Lanner 1982). In a study by Lanner (1982), protected cones that remained attached and yielded 347 seeds 1 year after maturing had 93 percent of the seeds containing decayed endosperms, presumably from exposure to the weather. Whitebark pine cones are not found on trees because of nearly complete removal or destruction due to seed predators. Intact cones were found only infrequently on the ground, and they contained only white-coated empty seeds (Tomback 1981). In some areas most or all of a cone crop is harvested by seed predators (Hutchins and Lanner 1982; Lanner 1982).

The Clark's nutcracker and red squirrels are the major dispersers of whitebark pine seeds (Arno and Hoff 1989; Hutchins and Lanner 1982; Lanner 1980; Lanner and Vander Wall 1980; Tomback 1978; 1982). Nutcrackers have a sturdy pointed bill ideal for picking apart whitebark cones. Upper portions of cone scales are easily broken off along a thin fracture zone. The scale base does not break away from the core of the cone thus fully exposing the seeds for easy removal by the nutcracker (Lanner 1982). Nutcrackers extract the seed and store them in their sublingual pouch, a saclike modification on the floor of the mouth (Bock and others 1973). The nutcracker appears to discriminate between good, aborted, insect-infected, or diseased seeds by rattling each seed in its bill before depositing the seed in its pouch, which holds over 100 seeds (Hutchins and Lanner 1982; Tomback 1978; Vander Wall and Balda 1977).

Clark's nutcrackers have been observed to carry whitebark pine seeds up to 14 mi from the seed source, although typical caching sites are close to the harvest site (Hutchins and Lanner 1982; Tomback 1978; Vander Wall and Balda 1977).

Nutcrackers cache groups of 1 to 25 seeds, one-half to 2 inches deep, on a variety of sites (McCaughey 1988). Cache sites are found on both well-drained and moist substrate, including soil, forest litter, gravel, rubble, cracks and fissures on exposed rock, and pumice (Hutchins and Lanner 1982; Tomback 1978; 1982). It is estimated that one nutcracker stores from 22,000 to over 98,000 whitebark pine seeds in years when seed is available (Hutchins and Lanner 1982; Vander Wall and Balda 1977). Food requirement estimates indicate that nutcrackers may store three to five times as many seeds as needed (Tomback 1983).

Squirrels harvest cones and seeds from mid-July to early November (Eggers 1986; Hutchins and Lanner 1982; Smith 1968). Squirrels store whitebark cones in middens and extracted seeds in caches on the forest floor, greatly reducing widespread dissemination of seed.

There are a variety of secondary dispersers known to disseminate whitebark pine seed. Grizzly and black bears raid squirrel middens to obtain whitebark seeds for food. Black bears may climb trees to harvest cones (Craighead and others 1982; Hammon 1983; Tisch 1961). Only rarely do whitebark seeds pass through a bear's digestive tract intact, severely limiting the probability of dispersal in this manner (Mattson 1987; McCaughey 1987).

Other animals that harvest whitebark pine seed either from the cones directly or indirectly from the ground or other animal caches and may act as dispersal agents are: birds – William's sapsucker (*Sphyrapicus thyroideus*), hairy woodpecker (*Picoides villosus*), white-headed woodpecker (*P. albolarvatus*), mountain chickadee (*Parus gambeli*), white-breasted nuthatch (*Sitta carolinensis*), Cassin's finch (*Carpodacus cassinii*), red crossbill (*Loxia curvirostra*), pine grosbeak (*Pinicola enucleator*), Steller's jay (*Cyanocitta stelleri*), raven (*Corvus corax*), and the red-breasted nuthatch (*Sitta canadensis*); rodents – chipmunks (*Eutamias* sp.), deer mice (*Peromyscus maniculatus*), golden-mantled ground squirrel (*Spermophilus lateralis*), and the chickaree (*Tamiasciurus douglasi*) (Eggers 1986; Hutchins and Lanner 1982; Tomback 1978).

Germination

Seed Storage—Whitebark pine seeds vary in the length of time they can be stored under environmentally controlled conditions. Viability drops from an initial average of 50 percent down to 3 percent when stored from 11 to 20 years (Schubert 1954). Seed viability dropped from 24 percent at time of collection to 17 percent after being stored for 8 years, but dropped to 1 percent after 11 years of storage (Mirov 1946). Viability of seed, as related to storage time, is dependent on seed maturity when harvested, seed handling prior to storage, and methods and length of time of stratification for germination tests.

It is unknown how long whitebark pine seeds will remain viable under natural (cached) storage conditions. McCaughey (1988) found 1-year-old filled whitebark seeds buried within nutcracker caches containing germinants. Nearly 75 percent of these filled seeds germinated after stratification, indicating that whitebark seed remains viable for at least 2 years.

Seed Germination—Even under controlled conditions whitebark pine seed viability is highly variable, ranging from 0 to 75 percent. The recommended procedure for germinating whitebark pine seeds is to soak seeds in running tap water for 1 to 2 days and then, with moist seeds in plastic bags, stratify at 33 to 41 °F for 90 to 120 days (Krugman and Jenkinson 1974). The Coeur d'Alene Nursery in Idaho successfully uses the following procedures for both western white pine and whitebark pine:

A. Place seed in nylon mesh bags.
B. Soak seed for 48 hours in running tap water. Place nylon mesh bag in plastic bag.
C. Stratify for 100 days at 33 to 35 °F. Within that 100-day stratification time resoak the seed for 1 hour each week.
D. After 100 days, remove seed from stratification and surface dry.
E. Using a vacuum seeder, place 100 seeds on moist paper towels (kimpak) in each of four plastic trays.
F. Place trays in germinator and take counts.

Using these procedures, 1985 and 1987 seed lots (#6610 and #6653 respectively) of whitebark pine had 35 and 50 percent germination rates (USDA 1987).

Dormancy of whitebark pine seed is caused by embryo underdevelopment, physiological embryo dormancy, by the barrier of the seed coat and female gametophyte tissue to oxygen and water uptake, and possibly by deposition of growth inhibitors to the embryo by female gametophyte tissue (Pitel 1981; Pitel and Wang 1980).

Sulfuric acid treatment moderately improves germination of whitebark pine seeds; seedcoat clipping also increases germination. Sulfuric acid-treated seeds show a 6 percent improvement in germination and clipped seeds an 8 to 14 percent improvement over untreated seeds (Pitel and Wang 1980).

Seed dormancy can be reduced by increasing the length of time whitebark pine seeds are stratified. Germination increased from 0 to 4 percent for intact seeds and 0 to 30 percent for clipped seeds when stratification times increased from 20 to 60 days (Leadem 1985). Hoff (1980) obtained 34 percent germination of whitebark seed when

seeds were first cold stratified for 150 days and then the seedcoat cracked. Whitebark pine germination increased to 78 and 90 percent when clipped and stratified for 30 and 60 days respectively (Pitel 1981). Under field conditions, germination was 8 to 14 percent for intact seeds when naturally stratified for nearly 200 days (McCaughey 1988). Under natural conditions whitebark seed is covered with snow from early November to late May creating a 180 to 210 day cold stratification period.

Germination of whitebark pine seed is influenced by seed placement and type of seedbed. Table 2 shows preliminary results of a natural regeneration study of whitebark pine under field conditions (McCaughey 1988). Shading of 0, 25, and 50 percent did not have a significant effect on germination.

In nature, whitebark pine germination begins immediately after snow melt and continues through early September (McCaughey 1988; Tomback 1987). Most of the late germination may actually have germinated earlier in the summer but because of the slow growth characteristics and depth of caching it was not visible until later. Most natural germination occurs in Clark's nutcracker caches, although minor amounts of germination may be due to natural seed dissemination from fallen cones. Germination from seeds scattered on the ground is minimal because of heavy predation by red squirrels, mice, and chipmunks (Hutchins and Lanner 1982; McCaughey 1988).

Seedlings

Whitebark pine germinants are large compared to those of its conifer associates. Germinants produce five to 12 cotyledons growing to heights ranging from 1 to 4 inches tall. Forking of the mainstem occurred on 17 percent of whitebark germinants; 10 percent had a single fork and 7 percent had two forks (McCaughey 1988).

Seedling survival of whitebark pine is affected by a variety of biotic and microsite factors. Several causes of conifer seedling mortality are drought, insolation, birds and rodents, animal trampling, frost heaving, damping off fungi, insects, and poor root development (Hard and Rice 1979; Harrington and Kelsey 1979; Shearer 1980).

Vegetative Reproduction

Whitebark pine vegetatively reproduces through layering of lower branches along the ground surface. In the Bitterroot Range of Montana vegetative reproduction was

Table 2—Percent germination of whitebark pine seeds placed on the surface and buried 2-4 cm on mineral and litter seedbeds (n = 360 seeds per seed placement seedbed combination)

Seed placement	Seedbed: Mineral	Seedbed: Litter
	- - *Percent germination* - -	
On surface	3.9	0.0
Buried 2-4 cm	14.7	8.8

observed from layering of shrub-like whitebark (Arno 1981; Arno and Hoff 1989). Whitebark easily grafts on stock plants of whitebark and western white pine, although grafts grow fastest on western white pine (Johnson 1981).

GROWTH

Whitebark pine is a slow-growing tree when found at the upper limit of tree growth. It can compete with and even outgrow its conifer associates on better sites in southwest Alberta (Day 1967). Whitebark pine is long lived, surviving over 700 years and may attain 1,000 years (Arno and Hoff 1989; Luckman and others 1984). It tends to remain windfirm for longer periods than lodgepole pine (Day 1967; Luckman and others 1984).

Environment greatly affects growth of whitebark pine. At timberline, it grows extremely slowly, developing a shrublike appearance. In Wyoming, where whitebark forms climax stands, it attains heights from 30 to 90 ft tall with average stand diameters of 12 to 14 inches (Eggers 1986). The largest tree on record, based on height and diameter measurements, was 69 ft tall with a 105-inch diameter (AFA 1986). Several trees in Canada are from 80 to 100 ft tall with diameters ranging from 25 to 36 inches (Day 1967) and in northwest Montana whitebark trees from 100 to 110 ft tall are common in old stands on good sites (Arno 1989).

Growth and yield information is limited for whitebark because the species has typically occupied only a minor component in most commercial stands. Where whitebark forms a major component, stand productivity is usually low. In Montana, whitebark grows best in the *Abies lasiocarpa/Luzula hitchcockii* habitat type *Menziesia ferruginea* phase (Pfister and others 1977). Merchantable timber yield is low, about 10 to 20 ft^3/acre/yr in high elevation *Pinus albicaulis/Vaccinium scoparium* stands in Montana (Forcella and Weaver 1977). Yields were around 29 ft^3/acre/yr in the lodgepole pine-whitebark type in south-central Oregon (Hopkins 1979).

Biomass Production

Whitebark pine has a characteristic spreading crown when open grown and, in dense stands, has a crown shape similar to lodgepole pine's but with upswept upper crown development. There are several tree and stand characteristics of whitebark pine that interact in several ways resulting in varying biomass production depending on the situation (Weaver and Forcella 1977). Biomass production can be expressed as whole tree weight or as production of tree parts such as crown width (CW), live and dead crown weight, bole weight, foliage weight, and twig weight. Brown (1978) and Moeur (1981) developed several equations that predict biomass production of whitebark pine (table 3). Tree and stand characteristics used to develop prediction equations for biomass production are diameter at breast height (D), total tree height (H), crown length (CL), basal area of tree (BA), tree age (A), number of trees per acre (TPA), the relative diameter ($DREL=D/$quadratic mean stand diameter), and the crown ratio (R=[live crown length/H]*10).

LIGHT

Tolerance of whitebark pine to light competition is thought to change with stage of development. Whitebark is considered highly to somewhat shade intolerant during early juvenile growth but becomes more shade tolerant with age (Day 1967; Eggers 1986; Sudworth 1908). Whitebark pine has been rated very shade intolerant (Baker 1949), though McCaughey (1988) observed seedlings and saplings growing up through the canopies of subalpine fir and lodgepole pine indicating moderate tolerance at an early age. Arno (1989) has observed this moderate tolerance at all ages for whitebark pine. At later developmental stages, whitebark is less tolerant than subalpine fir, Engelmann spruce (*Picea engelmannii*), and mountain hemlock (*Tsuga mertensiana*) but more tolerant than lodgepole pine, limber pine, and subalpine larch (*Larix lyallii*) (Pfister and others 1977; Steele and others 1983).

INSECTS

There are a number of insects that damage whitebark pine. The mountain pine beetle (*Dendroctonus ponderosae* Hopkins) is the most important. Table 4 lists many of the insects that affect whitebark.

The mountain pine beetle displays host specificity between lodgepole pine and whitebark pine for the species in which it completed larval development. Extensive mortality in one or the other of the two host species does not result in comparable mortality in the other host (Baker and others 1971). Severe mortality in whitebark pine can occur during years when temperatures are favorable and beetle populations can increase (Baker and others 1971; McGregor and Cole 1985). Beetle populations usually build first in adjacent lower elevations where lodgepole pine is a major stand component and migrate up, eventually attacking the larger lodgepole pine and whitebark pine (McGregor and Cole 1985).

Table 3—Regression equations for predicting crown width, live and dead crown weight, bole and whole tree weight, foliage weight, and twig weights of whitebark pine (from: Brown 1978; Moeur 1981)

Tree component	Equation
Crown width (>3.5" D)	$LN(CW) = -0.91984 + 1.08137LN(D) - 0.07299LN(H) + 0.29786LN(CL)$
Crown width (<3.5" D)	$LN(CW) = 0.07049LN(H) + 0.28283LN(CL) + 0.04032LN(BA)$ (Moeur 1981)
Crown weight (>3.5" D)	$LN(WT) = 2.62251 + 2.08624LN(D) - 1.07705LN(H) + 0.69082LN(CL) - 0.30885LN(A) - 0.14210LN(TPA) + 0.39924LN(DREL)$
Crown weight (<3.5" D)	$LN(WT) = -2.81317 + 1.47513LN(D) + 0.22823LN(A) - 0.13550LN(TPA)$
Crown weight (live trees >1" D)	$WT = 0.65 + 0.06056(D^3) + 0.05477(D^2R)$
Crown weight (dead branches trees >1" D)	$WT = 0.001713(D^2CL) + 0.33$
Bole weight (<4" D)	$WT = 1.33 + 0.08614(D^2H)$
Whole tree (<15 ft H)	$WT = EXP[-2.876 + 2.175LN(H)]$
Foliage (indiv. branch)	$WT = -0.9265 + 2.292LN(D)$
Branches (0 to 0.24" D)	$WT = -1.844 + 1.915LN(D)$
Branches (0.25 to 0.99" D)	$WT = -1.008 + 2.664LN(D)$
Branches (1 to 2.99" D)	$WT = -2.180 + 3.351LN(D)$

Table 4—Known insect pests of whitebark pine (from: Arno and Hoff 1989; Bright 1968; Eggers 1986; Furniss and Carolin 1977; Hoff and McDonald 1977)

Species	Common name or type of insect
Dendroctonus ponderosa	Mountain pine beetle
Pityogenes knechtel	Secondary bark beetle
Pityogenes carinulatus	Secondary bark beetle
Pityogenes fossifrons	Secondary bark beetle
Pityophthorus aquilonius	Secondary bark beetle
Pityophthorus collinus	Secondary bark beetle
Ips spp.	Pine engraver
Argyrotaenia tabulana	Lodgepole needle-tier
Essigella gillettei	Aphid - needle feeder
Pineus coloradensis	Aphid - needle feeder
Puto cupressi	Mealy bug
Puto pricei	Mealy bug
Dioryctria	Cone worm
Eucosma	Cone worm
Conophthorus	Cone beetle
Conophthorus ponderosae	Cone insect

Table 5—Known pathogens of whitebark pine (from: Eggers 1986; Goward 1985; Hiratsuka and Funk 1976; Knutson and Tinnin 1981; Mathiasen and Hawksworth 1988; Smith 1972)

Species	Damage - affected area
Herpotrichia juniperi	Snow mold - foliage
Herpotrichia nigra	Snow mold - foliage
Neopeccia coulteri	Snow mold - foliage
Lophodermella	Needle cast - foliage
Lophodermium nitens	Needle cast - foliage
Bifusella linearis	Needle cast - foliage
Bifusella saccata	Needle cast - foliage
Gremmeniella abietina	Shoot blight - foliage
Cronartium ribicola	Blister rust - branch and stem
Arceuthobium americanum	Dwarf mistletoe - branch and stem
Arceuthobium cyanocarpum	Dwarf mistletoe - branch and stem
Lachnellula pini	Minor canker - branch and stem
Atropellis piniphila	Canker - branch and stem
Armillariella mellea	Shoestring root rot - root
Polyporus schweinitzii	Brown cubical butt rot - butt
Polyporus subacida	Spongy rot - butt
Phaeolus schweinitzii	Butt rot
Perenniporia subacida	Rot - root and butt
Phellinus pini	Decay - stem
Fomes annosus	Rot - root and butt
Ahtiana sphaerosporella	Lichen - bark

DISEASES

High-elevation stands of whitebark pine are not generally susceptible to most pathogens. White pine blister rust (*Cronartium ribicola*) introduced from Europe is the most serious disease affecting whitebark (Carlson 1978). Whitebark remains highly susceptible to white pine blister rust even on trees with disease-resistant parents (Hoff 1980). The severity and extent of an infection of blister rust depend mainly on weather patterns and to a lesser degree on the abundance of the alternate host *Ribes*. In the Yellowstone ecosystem of northwest Wyoming and south-central Montana blister rust incidence has remained at low levels even when *Ribes* populations are extensive in some areas. Ecological conditions in this area have probably limited rust spread (Carlson 1978). In the Pacific Northwest whitebark pine is the most susceptible of all host trees to white pine blister rust (Childs and Bedwell 1948). Extensive damage and mortality of whitebark pine to blister rust and secondary causes has been observed (Arno 1986).

There are a number of other pathogens that affect whitebark pine in a variety of ways. Table 5 lists most of the known pathogens found on whitebark pine.

HABITAT ASSOCIATES

Whitebark pine is found on a wide range of habitats. It occurs in 36 of the more than 50 forest habitat types in eastern Idaho-western Wyoming area, in 24 of 76 habitat/phase types in central Idaho, and in 46 of the 99 habitat/phase types in Montana (Pfister and others 1977; Steele and others 1981; 1983).

Little information is available on plant associates of whitebark pine at timberline. Where whitebark forms an overstory, the understory vegetation is usually dominated by *Vaccinium scoparium* (Weaver and Dale 1974). In the Rocky Mountains several other understory species commonly associated with whitebark pine are: *Hieracium gracile*, *Carex geyeri*, *Potentilla gracilis*, *Lupinus sericeus*, *Polygonum bistortoides*, *Castilleja rhexifolia*, *Poa alpina*, *Luzula hitchcockii*, *Phyllodoce empetriformis*, *Menziesia ferruginea*, *Xerophyllum tenax*, *Juncus parryi*, *Festuca idahoensis*, and *Erythronium grandiflorum*. The four most common associates of 57 plant species found in whitebark stands in Montana and Idaho were *Carex rossii*, *Abies lasiocarpa*, *Poa nervosa*, and *Arnica latifolia* (Forcella 1977). *Carex pensylvanica* and *Poa nervosa* are the most common undergrowth species in south-central Oregon (Hopkins 1979). In Alberta, *Juniperus communis* is the major understory plant associated with whitebark pine (Baig 1972).

Throughout whitebark's distributional range it grows in association with several tree species. Whitebark can be found growing with *Pinus contorta* var. *latifolia*, *Abies lasiocarpa*, *Picea engelmannii*, *Pinus flexilis*, *Pseudotsuga menziesii*, *Larix lyallii*, *Populus* spp., *Juniperus scopulorum*, *Abies magnifica* var. *magnifica*, *Abies magnifica* var. *shastensis*, *Pinus contorta* var. *murrayanna*, *Pinus monticola*, and *Pinus balfouriana* (Arno and Hoff 1989).

FIRE ECOLOGY

Wildfire plays an important role in creating the structure and plant diversity of the western forests. Little is known about how fire has shaped the subalpine and timberline habitats that contain whitebark pine. Fire intervals range from 60 to 300 years or more in the whitebark types of Montana (Arno 1980).

Lightning is the major cause of fires in most whitebark stands although accidental fires have resulted due to increased recreation activity in these forests (Arno and Hoff 1989). Fire intensity and resultant tree mortality are generally low in climax whitebark stands because of sparse ground fuels and cool-moist conditions. Fires are typically spotty in the pure whitebark types except when windy warm-dry conditions help fires spread both along the ground and through tree crowns (Arno and Hoff 1989).

Whitebark pine is considered a pioneering species on burned areas and is moderately fire resistant. Fire suppression over the past several decades has aided successional replacement of whitebark by shade-tolerant species thus reducing its distribution. Spreading surface fires help maintain whitebark communities on sites where they grow in association with subalpine fir and Engelmann spruce. Whitebark has a thin bark making it susceptible to fire injury from hot surface fires, but because of its open stand and low fuel characteristics it survives most surface fires. Subalpine fir and Engelmann spruce have properties that make them very vulnerable to fires of even low intensity (Crane and Fisher 1986; Fisher and Clayton 1983).

The mountain pine beetle and lower elevation forests play key roles in the fire ecology of whitebark pine. Mortality from the mountain pine beetle increases fuel loading, fire intensities, and crown fire potential. Fires starting in lower elevation forests, of higher density, spread up through climax whitebark communities to timberline (Arno and Hoff 1989). Open whitebark stands act as a firebreak unless stand and climate conditions are favorable for carrying the fire as was the case with the 1988 fires in Yellowstone National Park.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from John Joy originally given to Diana Tomback)—On large burned over whitebark pine stands does regeneration come from seed cached prior to the fire, seed cached only after the fire, or both?

A.—I believe that the majority of the regeneration would come from seed cached after the fire but because I have found that seed can remain in the ground for at least 2 years and still germinate, "some" germination could come from previously cached seed.

Q. (from Ron Lanner)—Since nobody has ever published a definitive report of germination from a fallen cone nor even that cones abscise: how do you suppose these myths got started?

A.—Ron Lanner himself has published information on whitebark cones surviving on the tree and showing no signs of abscising. The myth probably came about when people were not finding cones on the trees. The immediate assumption is that the cones had fallen off. Again, they did not find the cones on the ground and assumed that they had fallen apart. They did not consider the possibility that animal predation (Clark's nutcracker and squirrels) could completely eliminate all cones from all trees.

Q. (from Bill Shuster)—Any idea on why the recent downward trend in cone production? What factors affect production in whitebark?

A.— Knight and others (1987) cited declines in productivity probably due to (1) infestations of the pine beetle, which were first noted in 1982; (2) the inherent cyclic nature of whitebark pine cone production, which results in extremes approximately every 7 to 10 years; and (3) the effects of persistent adverse climatic conditions (drought). Past studies indicate that temperature and precipitation have a significant, but not dominant, effect on all stages of cone development. Insects may also play a role in influencing cone production of whitebark pine.

Q. (from unknown source)—Is there a fairly reliable method to tell the difference between whitebark pine and limber pine, in the field, if there are no cones present?

A.—No. The only reliable way is to microscopically examine cell differences within cross sections of the needles. There are so many variables to consider when you try to determine what a tree is. The elevation: high elevation usually means it is whitebark unless it is on a limestone substrate; low elevation probably means the tree is limber pine. In the Bridger Mountains I have found whitebark and limber growing on the same site and without the cones I couldn't tell them apart.

Q. (from Diana Tomback)—You mentioned that single boled whitebark pine grew "in close competition" with lodgepole pine. Are you suggesting there is a cause-effect relationship for growth form? Or do some conditions producing dense lodgepole forests produce a multi-trunk form?

A.—I believe there is a cause and effect relationship occurring in dense stands of lodgepole pine on the growth form of whitebark pine. I have on rare occasions seen multi-trunked whitebark in dense stands of lodgepole pine. I believe that as stand density increases the *probability* of a single stemmed whitebark pine occurring increases.

Q. (from Maria Ash)—Your seedling photos mostly show the cotyledons and juvenile leaves of 1-year-old germinants. Is it possible that these 1-year-old seedlings could appear older (for example, more foliage with fascicles forming by the end of the first growing season)?

A.—Yes. Lammas growth does occur giving a 1-year-old seedling the appearance of being 2 years old.

Q. (from Earle Layser)—Do you think that the "isolated" occurrence that you showed for whitebark in the southern Selkirks in NE Washington are pockets or remnant stands that escaped from the extensive extreme fires that burned that area in the early 1900's?

A.—With little knowledge about the area I cannot give a good answer to this question. If the fires left pockets of whitebark pine then the burned areas should be capable of growing whitebark. If whitebark is naturally coming back onto the burned areas then it is very likely that the fires created the remnant stands. If not then the pockets are probably due to some past geologic event.

Q. (from Stephen Harvey)—Cones initiate in fall, develop in the following summer . . . please finish the progression.

A.—Differentiation into vegetative and reproductive buds occurs during the bud set period. Male and female cones develop during the first summer with male cones producing pollen which then pollinates the female cones. The female cone is a "first year cone" about 1 inch long. During the next summer the female cone "second year cone" grows to full mature size ($1^1/_2$ to $3^1/_3$ inches long).

WHITEBARK PINE COMMUNITY TYPES AND THEIR PATTERNS ON THE LANDSCAPE

Stephen F. Arno
Tad Weaver

ABSTRACT

Within whitebark pine's (Pinus albicaulis) *relatively narrow zone of occurrence—the highest elevations of tree growth from California and Wyoming north to British Columbia and Alberta—this species is a member of diverse plant communities. This paper summarizes studies from throughout its distribution that have described community types containing whitebark pine and the habitat types (environmental types based on potential vegetation) it occupies.*

Whitebark pine is most abundant and widespread in the semiarid inland mountain ranges of the northwestern United States and southwestern Canada, where it occurs in a continuum of environmental situations. It can be (1) a fire-dependent, early seral component of spruce-fir forests on moist sites; (2) a persistent seral or minor climax associate in drier forest habitats; (3) a major climax species or the only tree under still drier or more wind-exposed conditions; or (4) a major component or sole dominant of krummholz communities above tree line.

The timberline landscape is a mosaic of cover types including windswept fellfields and grassy balds, wet meadows, snowdrift communities, and krummholz (shrublike conifers) and forest communities with various proportions of whitebark pine. Four factors explain much of the variation in cover types: (1) rugged topography, through its influence on microclimate; (2) differences in surface rockiness, ranging from boulder piles to moderately well-developed soils; (3) differences in substrate composition, with especially noteworthy changes occurring between calcareous and noncalcareous geologic parent materials; and (4) a patchwork of different disturbance histories in the aftermath of fires, bark beetle epidemics, blowdowns, or snow avalanches.

Whitebark pine communities also vary regionally, with changes in both climate and competing species. For example, in maritime mountain regions whitebark pine is unable to compete in the closed upper subalpine forest; it is, therefore, restricted to tree islands in the open heath parklands at timberline.

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INTRODUCTION

Whitebark pine (*Pinus albicaulis*) is a prominent species in the upper subalpine forest and timberline zones on high mountains of western North America. Here, a great variety of tree-dominated and nonarboreal communities form a complex vegetational mosaic on the rugged landscape. While few studies have provided detailed descriptions of these communities or the causes of their distributional patterns, it is possible to list the major community types and to specify the principal factors controlling the mosaic. An understanding of this environmental complex is needed to guide land management. For example, to prevent undesirable changes in water, wildlife, and recreational resources, we must be able to recognize and manage the impacts of recreation, grazing, mining, timber harvest, air pollution, greenhouse effects, and advanced forest succession linked to fire suppression.

The presence and dominance of whitebark pine depend on its environmental tolerances and on its competitive abilities. Its tolerances restrict it to relatively cool sites without extended drought. Its relatively low capacity to compete (table 1) restricts it to harsh sites where growth of more competitive trees is hampered by physical factors or, on better forest sites, by disturbance. In this paper

Table 1—Comparative tolerance of shade or competition for species associated with whitebark pine in the Inland Northwest (after Minore 1979)

Tolerance	Species
Very tolerant	Subalpine fir (*Abies lasiocarpa*)
	Mountain hemlock (*Tsuga mertensiana*)
Tolerant	Engelmann spruce (*Picea engelmannii*)
Intermediate or intolerant	Whitebark pine (*Pinus albicaulis*)
Very intolerant	Lodgepole pine (*Pinus contorta* var. *latifolia*)
	Alpine larch (*Larix lyallii*)

we examine, first, the variation in potential climax vegetation reflecting the habitat type (Daubenmire and Daubenmire 1968; Pfister and Arno 1980) as it changes locally with microclimate or substrate and regionally with macroclimate. Then, we address the role of temporal changes in the vegetation on a site after disturbance, since whitebark pine is seral in many habitat types. We conclude with a brief outline of regional classification schemes.

ENVIRONMENTAL CONTROLS

The patterns of distribution and relative dominance of whitebark pine and its associates on the mountain landscape are strongly influenced by topography (Arno and Hammerly 1984; Habeck 1987; Pfister and others 1977; Steele and others 1981, 1983). For example, slope orientation profoundly affects microclimate; north and east aspects are relatively moist and cool while south and west aspects are drier and warmer. Also, at increasingly higher elevations growing seasons become shorter and cooler.

Because it is relatively cold tolerant and relatively noncompetitive, whitebark pine's importance increases with elevation. In the lower subalpine habitat types (fig. 1) whitebark pine occurs in small amounts and primarily as suppressed saplings. In the colder, upper subalpine habitat types the establishment and growth of competing conifers are reduced. This allows whitebark pine to assume dominance on many sites.

In moist sites of the upper subalpine zone (for example, cirque basins) whitebark pine is a minor component of subalpine fir-spruce (*Abies lasiocarpa-Picea engelmannii*) stands except where it becomes a pioneer dominant after a severe fire, avalanche, or other major disturbance. Its early seral success is possible because of whitebark pine's superior hardiness in the harsh microclimate of the disturbed site and its introduction by the seed caching Clark's nutcracker (Tomback and others, this proceedings). Within 150 to 200 years, vigorous fir and spruce begin to replace the pine.

Conversely, on relatively dry sites in the upper subalpine forest, whitebark pine is a long-persisting seral associate in the subalpine fir habitat types (potential climax; fig. 1). Lodgepole pine (*Pinus contorta* var. *latifolia*) is also a seral associate in many of these stands. On the driest sites, subalpine fir is absent, lodgepole pine is seral, and whitebark pine assumes the climax role (Steele and others 1983).

In the alpine timberline zone, above the upper limit of continuous forest, whitebark pine often occurs in pure or mixed groves or tree islands. Any trees that can survive are considered part of the climax community (Arno and Hammerly 1984; Pfister and others 1977). Whitebark pine and its arboreal associates occur in a continuum of lifeforms at timberline. These range from large, singlestem trees to stunted multistemmed trees to flagged krummholz (tall shrub form) and cushion krummholz. Because whitebark pine is hardier, it often produces a taller life form than the associated subalpine fir.

In addition to cold timberlines, whitebark pine occurs at dry timberlines, which are subalpine forest-herbland ecotones. At dry timberlines, it may be associated with inland Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) or limber pine (*Pinus flexilis*).

Rugged topography adds small-scale site variations to the general zonal patterns. For example, sharp ridge crests in the upper subalpine forest are exposed to severe wind, which favors whitebark pine relative to fir and spruce. Rugged topography and resulting vegetation patterns influence the distribution of snow, which in turn affects soil moisture, soil development, and potential

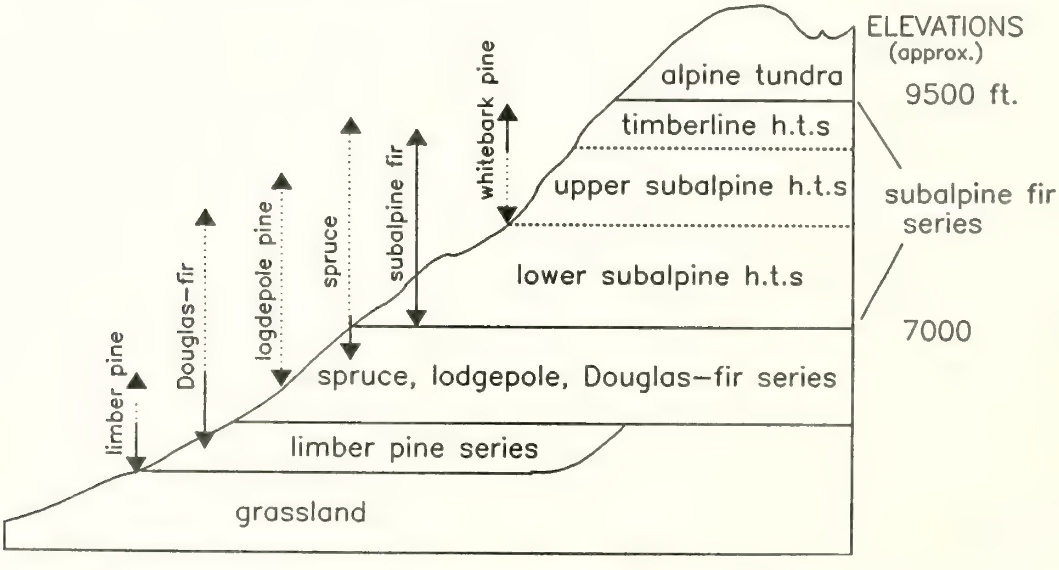

Figure 1—General elevational distribution of forest trees (arrows) and habitat type series (potential climax) on noncalcareous geologic types in south-central Montana. Solid portion of arrow indicates where a species is the potential climax, and dotted portion shows where it is seral. (Modified from Pfister and others 1977).

vegetation. Microsites receiving excessive snow often support wet meadow vegetation rather than trees. In contrast, microsites with deficient snow support semiarid grassland or other dry nonforest types. Sometimes contrasting snowdrift and dry microsites lie close to each other with a strip of whitebark pine in between, as in the "ridgetop ribbon forest" described by Arno and Hammerly (1984).

Edaphic factors also influence the distribution of whitebark pine in the rugged high-mountain terrain. For example, whitebark pine may be abundant on talus slopes or bedrock outcrops, but scarce on surrounding sites with deeper soils, where other conifers are more competitive.

Changes in substrate (surface geologic type) can also have a profound effect on whitebark pine communities. The contrast between calcareous (usually limestone) and noncalcareous substrates provides a dramatic example. Limestone often weathers to produce an excessively well-drained soil that limits growth of conifers (Goldin 1976; Pfister and others 1977). In especially dry regions (for example, in northern Nevada and eastern California), whitebark pine is largely confined to noncalcareous substrates (Harlow and Harrar 1958; Weaver and Dale 1974). In most regions, however, whitebark pine occurs on both calcareous and noncalcareous substrates. Calcareous sites support open pine stands with herbaceous undergrowth, while adjacent noncalcareous sites have dense mixed conifer stands with seral whitebark pine and an undergrowth of low *Vaccinium* (huckleberry or whortleberry) shrubs (Arno and Hammerly 1984; Pfister and others 1977).

REGIONAL VARIATIONS

On a larger scale, the composition and distribution of whitebark pine communities vary based on regional differences in climate, topography, and competitive relationships of subalpine tree floras. Whitebark pine communities are extensive and diverse in the drier inland mountain ranges. However, their abundance declines southward in California, perhaps in response to increasing length of summer drought. In wet regions, such as the crest of the northern Cascade Range and the British Columbia coastal ranges, whitebark pine occurs only in open timberline habitats and it is a minor constituent there. In these wet oceanic mountains, whitebark pine's growth is slow and its ultimate tree sizes are small. It is essentially absent from the dense upper subalpine forest, apparently because of an inability to compete with the shade-tolerant mountain hemlock (*Tsuga mertensiana*), subalpine fir, and Pacific silver fir (*Abies amabilis*). At these timberlines, dense heath (*Phyllodoce* and *Cassiope*) hinders conifer regeneration. Whitebark pine is a minor component of the conifer invasion that does occur in timberline heathlands during especially dry summers (Brink 1959; Franklin and others 1971).

Whitebark pine is abundant in regions having humid, snowy winters and long dry periods in summer, such as California's high Sierra Nevada and the inland mountains of the northwestern United States. Its abundance and vigorous growth in semiarid regions and on topographically dry sites suggest that it is more drought resistant than other northwestern subalpine trees.

The abundance of whitebark pine decreases as summer precipitation increases northward in the inland Northwest. For example, July-August precipitation in the upper subalpine zone averages about 2 inches (5 cm) in central Idaho, where the species is very abundant, and 5 to 6 inches in the latitude of Kootenay and Banff National Parks, where it is generally a minor component of the high-country vegetation (Arno 1970). Presumably this occurs because whitebark pine's competitors—subalpine fir, spruce, mountain hemlock (in the Selkirks), and (locally) alpine larch (*Larix lyallii*)—are more vigorous in the more humid environment. Physiological investigations of drought-sensitive alpine larch (Richards 1981; Richards and Bliss 1986) explain its inverse distribution. Despite extensive timberline habitat, alpine larch occurs only north of latitude 45.5° N., where it is confined to moist north-facing slopes. In contrast, northward into Canada it becomes abundant on southern exposures (Arno and Hammerly 1984).

Whitebark pine is absent from the high-desert mountains east and south of the Sierra Nevada, at least in part because this species is not as tolerant of year-round aridity as are limber pine and Great Basin bristlecone pine (*Pinus longaeva*). The current southern distributional limits of whitebark pine from California to the central Rockies may also result in part from inadequate seed distribution to isolated mountain habitats during alternating glacial and warm climates of the Pleistocene.

Thus, in the wettest mountain regions whitebark pine is narrowly confined to the timberline zone and to open rocky subalpine sites. In contrast, in drier regions where drought hampers competitors (notably in the dry-summer inland mountains of the northwestern United States), whitebark pine is often a major component of both the upper subalpine forest and the timberline zone, encompassing about 2,500 ft (760 m) in elevation. In the Sierra Nevada whitebark pine is generally confined to timberline but is often abundant there.

ROLE OF DISTURBANCE

Disturbances are important in shaping the structure of all whitebark pine communities, and natural disruptions are vital to the perpetuation of whitebark pine in the habitat types where it is seral. In the timberline zone, the climate is so harsh and limiting for tree growth that climatic disturbances (such as damaging winds, ice storms, snowloads, summer frost, and winter desiccation) prevent stand closure and thereby allow competition-intolerant species like whitebark pine to coexist indefinitely with their tolerant competitors (Arno and Hammerly 1984; Franklin and Dyrness 1973; Pfister and others 1977). Conversely, in subalpine forest habitats, whitebark pine's perpetuation depends upon occasional disturbances. Without disturbance, succession will lead to dominance by subalpine fir, spruce, or mountain hemlock.

In large portions of the inland northwestern United States, the area covered by seral whitebark pine communities has diminished in recent decades. Its decline is due to successional replacement linked to fire suppression and aggravated by epidemics of mountain pine beetle and white pine blister rust (Arno 1986; Kendall and Arno, this proceedings).

Prior to 1900, fires at intervals averaging between 50 and 350 years were widespread and were important in perpetuating seral whitebark pine communities (Arno 1986; Morgan and Bunting, this proceedings). These often burned in a patchy pattern with differential severities. Both light surface fires and stand replacing fires favor whitebark pine in relation to its shade-tolerant competitors. High-intensity, stand-replacing fires in thick subalpine fir-spruce forests often allow whitebark pine to become established as a result of nutcracker seed caching. After establishment, some of these seral whitebark pine communities have been perpetuated by low-intensity fires that killed understory fir and spruce.

As a result of fire suppression during the 1900's, natural fire cycles in seral whitebark pine communities have been postponed (Arno 1986), so this species is being replaced by its competitors. Even management programs that allow some natural fires to burn are probably insufficient for mimicking whitebark pine fire cycles of the past. The most effective fires in the highly discontinuous whitebark pine habitats (atop isolated high ridges) were ones that spread over large expanses—hundreds of thousands of acres. However, most whitebark pine habitats lie near developed or commercially utilized lands where such massive fires are not tolerable politically, even in wilderness areas or National Parks.

Fire suppression during this century has no doubt resulted in a decrease in the establishment of new whitebark pine communities. These young stands are needed to compensate for aging stands in which whitebark pine is being replaced successionally. Avalanches and severe blowdowns also create open microenvironments that allow whitebark pine to enter as a pioneer species. These disturbances are no substitute for fire, however, because they produce only small areas suitable for seral whitebark pine forests and they fail to reduce competition from understory trees and shrubs.

Mountain pine beetle epidemics are another influential natural disturbance that tends to kill overstory whitebark pines and enhance succession toward domination by subalpine fir (Bartos and Gibson, this proceedings; Kendall and Arno, this proceedings). Similarly, white pine blister rust, an introduced disease, severely injures and kills whitebark pine, hastening succession toward dominance by shade-tolerant conifers (Hoff and Hagle, this proceedings; Kendall and Arno, this proceedings).

COMMUNITY TYPES AND HABITAT TYPES

A variety of reports describe whitebark pine communities of almost every State and Province occupied by the tree (table 2). Whitebark pine habitats are abundant, diverse, and best documented in the inland northwestern United States (Cole 1982; Forcella 1977, 1978; Pfister and others 1977; Steele and others 1981, 1983; Weaver and Dale 1974; and other studies listed in table 2). Three remarkably consistent community complexes appear repeatedly in this region—extending from western Wyoming and northeastern Oregon to the southernmost portions of British Columbia and Alberta.

First, on the driest sites and in arid mountain ranges, communities dominated by whitebark pine (both seral and potential climax) are abundant. At the highest elevations, in cold-moist situations, the undergrowth is usually dominated by *Vaccinium scoparium*. Under progressively

Table 2—Principal publications and theses describing whitebark pine communities, listed by State and Province. Complete citations appear in the References section

Alberta	Achuff 1989; Baig 1972; Ogilvie, this proceedings
British Columbia	Achuff 1989; Brink 1959; McAvoy 1931; Ogilvie, this proceedings; Selby and Pitt 1984
California	Barbour 1988; Cooke 1940, 1955; Klikoff 1965; Sawyer and Thornburgh 1977; Taylor 1976; Vale 1977
Idaho	Steele and others 1981, 1983; USDA Forest Service 1989
Montana	Arno 1970; Craighead and others 1982; Forcella 1977, 1978; Pfister and others 1976, 1977; USDA Forest Service 1989; Weaver and Dale 1974
Nevada	Loope 1969
Oregon	Cole 1982; Franklin and Dyrness 1973; Hall 1973; Hopkins 1979; Jackson and Faller 1973; Lueck 1980
Washington	Agee and Kertis 1987; Arno 1970; del Moral 1979; Franklin and Dyrness 1973; Williams and Lillybridge 1983
Wyoming	Forcella 1977; Gruell 1980; Steele and others 1983;

drier conditions, the characteristic undergrowth changes to *Carex geyeri, Juncus parryi, Arnica cordifolia*, and, finally, *Festuca idahoensis*.

Second, in average mountain habitats of the inland Northwest, whitebark pine stands are codominated by subalpine fir and, at lower elevations, by lodgepole pine. The characteristic undergrowth ranges from *Phyllodoce empetriformis* and *Luzula hitchcockii* in moist situations to *Xerophyllum tenax, Vaccinium scoparium, Carex geyeri*, and *Ribes montigenum* on increasingly drier sites.

Third, moist subalpine forest sites often have whitebark pine as a seral component mixed with Engelmann spruce (*Picea engelmannii*), subalpine fir, and, at lower elevations, lodgepole pine. Alpine larch and mountain hemlock can be constituents in certain localities. Characteristic undergrowth includes numerous wet-meadow forbs and sedges, and the shrubs *Ledum glandulosum, Phyllodoce empetriformis, Menziesia ferruginea*, and *Rhododendron albiflorum*.

In the continental climate of western Wyoming and central Montana, whitebark pine is the potential climax tree in several subalpine forest habitat types as well as being a seral associate in several others (table 3). In the inland maritime climate found west of the continental divide in Montana, whitebark pine is seral except in the timberline zone (table 4).

Northward in the Rocky Mountains of Alberta and British Columbia, whitebark pine remains widespread but is less often a dominant species. Achuff (1989) and Ogilvie (this proceedings) provide detailed descriptions of whitebark pine communities in Canada. In Alberta, whitebark pine is most common in the timberline zone as a codominant with subalpine fir, spruce, and sometimes with alpine larch (Baig 1972). Characteristic undergrowth includes *Phyllodoce empetriformis* in moist sites along or near the Continental Divide (inland-maritime zone); *P. glanduliflora* in comparable sites in mountains farther inland (east); *Vaccinium scoparium* on well-drained sites, and *Juniperus communis* on the driest south-facing slopes.

The importance of whitebark pine increases from wet to dry sites in the Cascade Range. In the rain shadow of the Washington Cascades on the granitic Stuart Range, whitebark pine is abundant in the upper subalpine forest and the timberline zone. Timberline communities are dominated by whitebark pine on dry sites and warm aspects and by alpine larch in moist-cool situations (del Moral 1979) as they are in some moist mountain ranges of western Montana (Arno and Habeck 1972). In the Stuart Range, relatively moist whitebark pine-alpine larch communities have an undergrowth of *Vaccinium*

Table 3—High-elevation habitats of western Wyoming arranged approximately on a gradient of decreasing site moisture. Competitive status and abundance of whitebark pine and its associates are shown (modified from Steele and others 1983)

Site moisture	Habitat type[1]	Tree species[2] *Pinus albicaulis*	*Abies lasiocarpa*	*Picea engelmannii*	*Pinus contorta*	*Pinus flexilis*	*Pseudotsuga menziesii*	*Populus tremuloides*
Wet								
↑	PIEN/VASC	(S)	c	C	(S)	(s)		
	PIEN/CALE	s	c	C	s			
	ABLA/VAGL, VASC	s	C	S	S			
	ABLA/VASC, PIAL	C	C	S	S		(s)	
	ABLA/VASC, VASC	s	C	S	S			
	ABLA/ARLA	(S)	C	S	(S)		(S)	(S)
	ABLA/THOC	s	C	S	S		S	(S)
	ABLA/JUCO	s	C	(S)	S	s	(S)	
	ABLA/RIMO, RIMO	s	C	S	(s)			
	ABLA/RIMO, PIAL	C	C	c				
	ABLA/ARCO, SHCA	s	C	s	S	s	s	s
	PIAL/VASC	C	c	c	C			
	PIAL/CAGE				(C)			
	PIAL/JUCO	C			C	s		
	PIAL/CARO	C	(c)	(c)	(C)	(s)		
↓	PIAL/FEID	C						
Dry								

[1]Abbreviations consist of the first two letters of the genus and species names. Undergrowth species are: ARCO = *Arnica cordifolia;* ARLA = *A. latifolia;* CAGE = *Carex geyeri;* CALE = *Caltha leptosepala;* CARO = *Carex rossii;* FEID = *Festuca idahoensis;* JUCO = *Juniperus communis;* RIMO = *Ribes montigenum;* SHCA = *Shepherdia canadensis;* THOC = *Thalictrum occidentale;* VAGL = *Vaccinium globulare;* VASC = *V. scoparium.*

[2]C = climax dominant; S = seral dominant; c = minor climax species; s = minor seral species; () = in part of the habitat type only.

Table 4—Typical high-elevation forest zonation in west-central Montana showing the competitive status and abundance of whitebark pine and its associates (modified from Pfister and others 1977)

			Stand components[2]					
Elevational zone	**Moisture**	**Habitat types**[1]	***Pinus albicaulis***	***Abies lasiocarpa***	***Picea engelmannii***	***Larix lyallii***	***Pinus contorta***	***Pseudotsuga menziesii***
Timberline zone	Dry sites	PIAL	C	—	—		—	—
		PIAL-ABLA	C	C	c			
	Moist sites	LALY-ABLA	C	C	c	C		
Upper subalpine forest	Dry sites	ABLA-PIAL/VASC	S^{300y}	C	s		—	—
		ABLA/LUHI	S^{250y}	C	s		S^{200y}	—
	Moist sites		S^{200y}	C	S^{400y}	s	s	—
Lower subapline forest	Dry sites	ABLA/XETE, VASC	s	C	s	—	S	s

[1]Abbreviations consist of the first two letters of the genus and species names. Undergrowth species are: LUHI = *Luzula hitchcockii*; VASC = *Vaccinium scoparium*; XETE = *Xerophyllum tenax*.
[2]C = climax dominant; S = seral dominant for number of years (as indicated) after fire or other disturbance; c = minor climax species; s = minor seral species.

myrtillus, which is ecologically similar to *V. scoparium* (del Moral 1979). With increasing dryness, whitebark pine communities have undergrowths characterized by *Lewisia columbiana*, *Phlox diffusa*, *Juniperus communis*, and *Penstemon davidsonii*.

In the excessively well-drained pumice of the Oregon Cascades, whitebark pine communities are characterized by sparse undergrowth. On sites with average moisture conditions, undergrowth is typically *Penstemon davidsonii*; in wetter microsites *Vaccinium scoparium* and *Luzula hitchcockii* are characteristic (Jackson and Faller 1973; Lueck 1980). On coarse volcanic substrates in south-central Oregon, Hopkins (1979) described two community types (= habitat types) in which whitebark pine and lodgepole pine are the climax dominants and the principal undergrowth is *Carex pensylvanica*, *Poa nervosa*, and *Penstemon laetus*.

Southward on the Cascade-Sierra Nevada axis, whitebark pine is common but largely confined to timberline communities in northern and central California. Subalpine fir and Engelmann spruce are essentially absent, and the timberline communities tend to be quite open, with only sparse, scattered undergrowth (Barbour 1988). These communities consist of mixtures of whitebark pine with mountain hemlock on moist sites and with Sierra lodgepole pine (*Pinus contorta* var. *murrayana*), western white pine (*Pinus monticola*), and foxtail pine (*P. balfouriana*) on drier sites.

The whitebark pine zone is often made up of an intricate pattern of community types dominated variously by tall or dwarf trees, shrubs, subalpine herbs, or alpine tundra plants. These community mosaics and their microenvironmental controls are little studied. One exception is del Moral's (1979) work in the Stuart Range. Another is Pfister and others' (1976) quantitative description and map of an extensive whitebark pine community mosaic in the Scapegoat Wilderness of northwestern Montana. Their map (fig. 17 in Craighead and others 1982) differentiated six habitat types and phases containing major amounts of whitebark pine and several habitat types in which whitebark pine is a minor component. The map units were characterized with constancy and coverage data for forest community types (both postfire and mature) as well as associated subalpine grassland, wet meadow, and avalanche community types (table 5). The topographic and edaphic controls of the major whitebark pine types (table 6) were identified as a guide for vegetation mapping throughout the study area. Many more similar studies are needed before we hope to understand the dynamics of whitebark pine community mosaics.

Table 5—Constancy (in percent ÷ 10)—and average percent canopy cover, in (), for six habitat types in the Scapegoat Wilderness, MT, containing whitebark pine (from Pfister and others 1976; habitat types from Pfister and others 1977) (LUHI = *Luzula hitchcockii*; MEFE = *Menziesia ferruginea*; VASC = *Vaccinium scoparium*)

Habitat type and phase:	ABLA-PIAL/ VASC	ABLA/LUHI- VASC	ABLA/LUHI- MEFE	PIAL-ABLA	PIAL-ABLA snowdrift	LALY-ABLA
Computer map code:	820	831	832	850	850D	860
No. of sample stands:	13	8	2	4	2	3
TREES						
Abies lasiocarpa	9(39)	10(48)	10(65)	10(44)	5(4)	10(15)
Larix occidentalis						10(27)
Picea spp.	8(18)	8(27)	10(16)	8(7)	5(2)	7(13)
Pinus albicaulis	10(36)	10(30)	10(25)	10(47)	5(5)	10(15)
Pinus contorta	4(4)	1(10)				
Pseudotsuga menziesii	4(4)					
SHRUBS						
Alnus sinuata			5(4)			
Juniperus communis	4(7)			5(2)		
Ledum glandulosum		1(40)	10(10)			
Menziesia ferruginea	2(2)	4(3)	10(30)			
Ribes lacustre	3(1)	1(0)		2(0)		
Shepherdia canadensis	1(0)			2(0)		
Vaccinium caespitosum	1(0)					
Vaccinium globulare	2(30)	1(0)				
Vaccinium scoparium	7(38)	10(54)	10(45)	5(75)	5(10)	10(47)
PERENNIAL GRAMINOIDS						
Calamagrostis rubescens	2(10)					
Festuca idahoensis	1(20)			5(1)		
Luzula hitchcockii		10(11)	10(10)	8(2)		10(18)
PERENNIAL FORBS						
Cirsium foliosum	5(1)			8(1)		
Fragaria spp.	4(3)					
Heracleum lanatum	1(2)			2(0)		
Lomatium dissectum	1(0)					
Senecio triangularis	3(1)	1(0)		2(2)		
Thalictrum occidentale	4(22)	1(0)		8(17)		
Valeriana sitchensis	3(3)	3(2)		5(1)		
Viola orbiculata	1(0)		5(2)			
Xerophyllum tenax	8(38)	6(30)	5(30)			8(5)

Table 6—Topographical distribution of habitat types containing whitebark pine on noncalcareous and calcareous (limestone) substrates in the Scapegoat Wilderness, synthesized from Pfister and others (1976)

Environmental gradient	Habitat type and phase (Pfister and others 1977)	Geologic substrate: Noncalcareous Elevation	Noncalcareous Aspect	Calcareous Elevation	Calcareous Aspect
		Feet		*Feet*	
Warm/dry	PIAL and subalpine grasslands	[1]—	—	7,000-7,800	S
↑	ABLA-PIAL/VASC	—	—	7,000-8,000	all
	ABLA/LUHI-VASC	7,300-7,800	all	—	—
	ABLA/LUHI-MEFE	7,300-7,500	N&E	—	—
↓	PIAL-ABLA	7,800-8,300	NW,W, S, SE	8,000-8,500	all
Cold/wet	LALY-ABLA	7,700-8,600	N&E	—	—

[1]— = absent or scarce.

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WHITEBARK PINE ON THE MOUNT WASHBURN MASSIF, YELLOWSTONE NATIONAL PARK

David J. Mattson
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ABSTRACT

Habitat distribution and stand dynamics of whitebark pine (Pinus albicaulis) *within the whitebark pine zone of the Mount Washburn massif, Yellowstone National Park were investigated as part of a study of relationships among grizzly bears, red squirrels, and whitebark pine. Distribution of whitebark pine and whitebark pine habitat types was positively associated with increased site coldness and wind exposure. Subalpine fir* (Abies lasiocarpa) *and Engelmann spruce* (Picea engelmannii) *were relatively intolerant of wind exposure. Whitebark pine and lodgepole pine* (Pinus contorta) *were principal seral species and competitors in the whitebark pine zone. Lodgepole pine replaced whitebark pine on the warmest sites of the zone. Whitebark pine was climax because of its ability to tolerate extreme site conditions rather than shade, and so was climax only on sites with the most extreme wind exposure at high elevations where other tree species could not survive. On the harshest sites whitebark pine recruitment into the overstory was near zero, but proportionately increased with site amelioration. Fire frequency in our study area was estimated to be 250 years, although stand replacement fires occurred somewhere in our study area at average 80-year intervals.*

INTRODUCTION

Relatively little is known about the autecology and stand dynamics of whitebark pine (*Pinus albicaulis*), especially in the lower portions of its zonal distribution where it grows in competition with other tree species. Forcella (1978), Forcella and Weaver (1977), and Weaver and Dale (1974) reported on the environment, productivity, and flora of whitebark pine-dominated stands in the Yellowstone area. However, their work was restricted to higher elevation stands where other tree species were a minor component and not a competitive factor.

In 1984 the Interagency Grizzly Bear Study Team (IGBST) initiated a study designed to investigate relationships among grizzly bears (*Ursus arctos horribilis*), red squirrels (*Tamiasciurus hudsonicus*), and whitebark pine. As part of this study, distribution and stand dynamics of whitebark pine were investigated in two study areas in the Yellowstone ecosystem. These study areas included the full spectrum of whitebark pine's zonal and habitat distribution.

In this paper we report results from our Mount Washburn study area that pertain to habitat distribution and competitive relationships of whitebark pine and stand dynamics within the whitebark pine zone. The whitebark zone is defined here as the geographical and elevational zone where whitebark pine is represented from variously isolated to nearly exclusive. Reinhart and Mattson (this proceedings) report results that pertain to red squirrel habitat relationships within the whitebark pine zone.

STUDY AREA

Our study area was located in Yellowstone National Park on the Mount Washburn massif, at 44°45' latitude. The study area was between 8,000 and 9,600 ft elevation and encompassed most of the elevational distribution of whitebark pine and most major habitat types of the whitebark pine zone in the Yellowstone area.

METHODS

We delineated and mapped stands using 1:20,000 color aerial photographs and USGS 15-ft topographic maps. We identified stands by discernible differences in stand structure and composition and by marked topographic clines. Each stand was classified according to standard habitat type (Steele and others 1983) and successional cover type (Despain 1986) classifications. (For habitat type and cover type nomenclature and acronyms used in this paper see appendixes A and B).

We sampled each stand with five to 26 systematically placed variable-radius standard forest inventory plots (Husch 1963:160). We used basal area factors of 20 and 40, and measured the diameter of all trees in the plot. Each tree was identified by species and whether dead or alive. Age and 10-year growth increment were recorded for each species and diameter class at each plot from increment cores. Stem densities and basal area were calculated by standard procedures for variable radius plots (Husch 1963).

We also calculated mortality rates by stem-diameter classes. These rates were based on approximately 10 years of mortality preserved in standing dead stems. Some bias in our calculated mortality rates was because

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of movement of some live stems into a larger diameter class, while historical mortalities of those cohorts were attributed to the next smaller diameter class. Because of this likely bias and because mortality was spread over an extended time, calculated mortality rates are better viewed as an index, or at best a 10-year rate.

Stand and disturbance ages were estimated from examination of individual tree ages. Age was corrected for breast height by adding 20 years (Bunting 1989; Cole 1989). The oldest trees in a stand, regardless of species, were considered to best reflect stand age. Ages of stand disturbances were assumed to correspond to the oldest stand or individual tree ages.

We calculated several synthetic indices for our analysis of species and type distributions with respect to environment factors. Site radiation (*SR*) was derived from scaling (0 to 1.0) June 22 solar radiation (X_1) on site:

$$SR = (X_1 - 733)/100 \quad (1)$$

June 22 radiation (cal/cm²/day) was taken from tables that incorporated the effects of slope and aspect (Buffo and others 1972). Site warmth (*SW*) incorporated effects of elevation (X_2 in meters) and *SR* by adding *SR* and an inverse of scaled elevation (*E*):

$$E = (2896 - X_2)/609.6 \quad (2)$$

$$SW = E + SR \quad (3)$$

Wind exposure (*WE*) was also indexed by incorporating the effects of aspect and slope. Frequency of winds >5 mph by aspect class was taken from Dirks and Martner (1982), from their Upper Rendezvous site. Frequencies were applied to individual stands based on their aspect and multiplied by the sine of degrees of site slope. The resulting value (X_3) was scaled from 0 to 1.0 to derive *WE*:

$$WE = (X_3/100) - 0.09)/19.91 \quad (4)$$

Site favorability (*SF*), which was not used in this paper but was used by Reinhart and Mattson (this proceedings), was the difference of *SW* and ½ weighted *WE*:

$$SF = SW - \tfrac{1}{2}\, WE \quad (5)$$

RESULTS

Species Distribution

We examined distributions of the four major tree species in our study area with respect to site warmth and summer wind exposure. Distributions of whitebark pine and lodgepole pine (*Pinus contorta*) were typically more sensitive to site warmth; distributions of subalpine fir (*Abies lasiocarpa*) and Engelmann spruce (*Picea engelmannii*) were more sensitive to wind exposure (fig. 1). Whitebark pine basal area increased with site coldness; this was most pronounced between warmth indices 1.25 and 1.00, and was highest on the coldest sites with moderate wind exposure. Lodgepole pine basal area increased with site coldness, most dramatically between warmth indices of 1.15 to 1.30. Basal areas of both subalpine fir and Engelmann spruce decreased with wind exposure to near zero on the most wind-exposed sites. Basal area of subalpine fir also decreased on the coldest and increased on the warmest protected sites. Engelmann spruce exhibited maximum local basal area on the coldest protected sites, where basal areas of both subalpine fir and lodgepole pine decreased, and at warmth indices between 1.00 and 1.25, where the most pronounced transition from lodgepole pine to whitebark pine occurred.

The distribution of whitebark pine basal area with respect to site warmth was exponential (fig. 2), with less variation in basal area on warmer sites. The lowest basal areas of whitebark pine occurred on sites with warmth indices >1.25. Only two of these warmest sites had whitebark pine basal area >50 ft²/acre.

Cover Type Distributions

Cover types reflect the relative stand structure of tree species and follow the descriptions of Despain (1986). Distribution of cover types followed environmental distribution of individual species (fig. 3). Lodgepole pine cover types were restricted to warmer, lower elevation sites. Whitebark pine cover types occurred on the coldest or highest elevation sites. Midsuccessional (LP2 and WB2) cover types occupied sites with greater summer radiation compared to later-successional cover types. Climax whitebark pine stands (WB), not shown in figure 3, were restricted to more open, high-elevation sites with high wind exposure.

Habitat Type Distributions

Distribution of habitat types (h.t.'s) in the whitebark pine zone was clearly associated with summer wind exposure (fig. 4). The whitebark pine (PIAL) series and the ABLA/SPBE h.t. were restricted to sites with high wind exposure (see appendix A for h.t. nomenclature). Only a few stands of the ABLA/VASC-PIAL phase and ABLA/THOC h.t. occurred on sites with high wind exposure; otherwise these and the ABLA/VAGL-VASC and ABLA/VASC-VASC types were restricted to sites with low to moderate exposure.

Among h.t.'s associated with high wind exposure, the ABLA/SPBE type was restricted to lower elevation sites of the whitebark pine zone with less incident radiation, and the PIAL series to higher elevations. Within the PIAL series, the PIAL/FEID h.t. was characteristic of cold sites and an as yet undefined, tentatively identified, PIAL/THFE h.t. was characteristic of warmer sites.

Distribution of habitat types on sites with lower wind exposure exhibited greater overlap (fig. 4). Distribution of the ABLA/VASC-VASC and ABLA/THOC types and the ABLA/VASC-PIAL and ABLA/VAGL-VASC types, respectively, overlapped considerably along elevation and summer radiation gradients. Core distribution of the ABLA/VASC-VASC and ABLA/THOC types was on the warmest sites of the whitebark pine zone. Core distribution of the ABLA/VAGL-VASC type overlapped almost completely with the ABLA/VASC-PIAL type on cool sites of the zone; the coldest sites were found exclusively on the ABLA/VASC-PIAL habitat type.

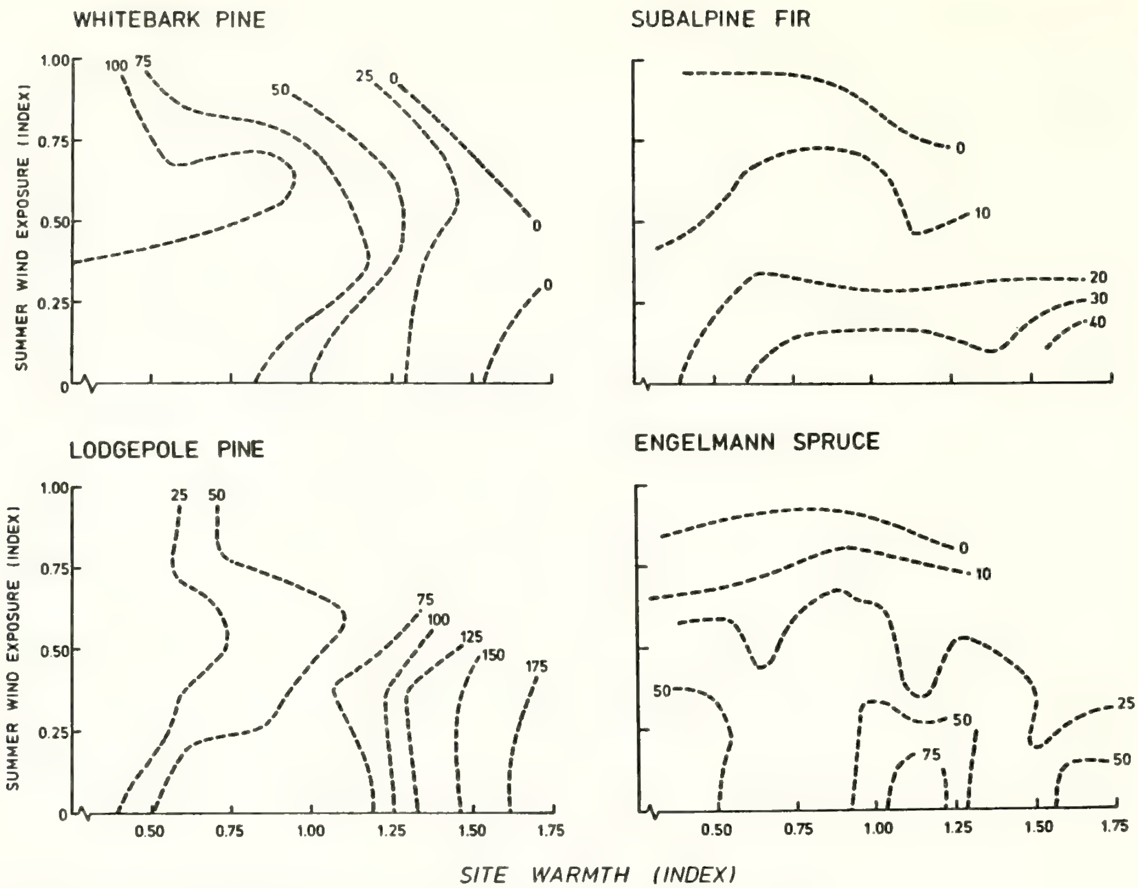

Figure 1—Basal area (ft²/acre) distribution of four major study area species with respect to site warmth and summer wind exposure.

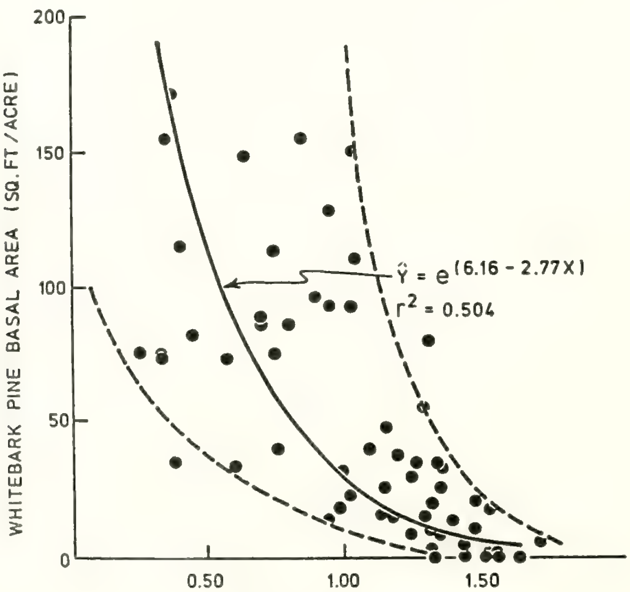

Figure 2—Relationship of whitebark pine basal area, on sites with low to moderate summer wind exposure, to site warmth.

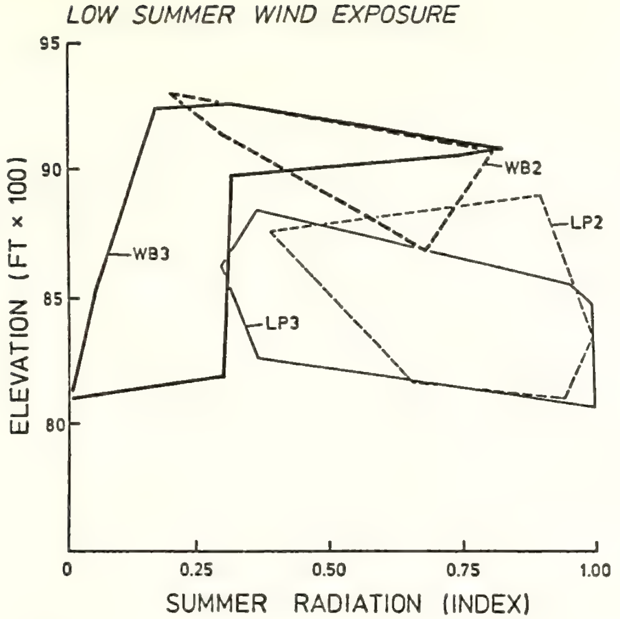

Figure 3—Distribution of cover types with respect to summer radiation and elevation, for sites with low to moderate summer wind exposure.

Growth and Age by Diameter Class

Cross-sectional growth rates of all four species tended to decline with increased diameter (fig. 5). This trend was most evident for Engelmann spruce and subalpine fir. Among all but the largest trees (≥19.7 inches d.b.h.) subalpine fir and Engelmann spruce were growing faster than whitebark pine and lodgepole pine. Among medium-diameter trees (9.8 to 13.8 inches d.b.h.) subalpine fir tended to be growing faster than Engelmann spruce.

Several distinctive patterns were evident in the distribution of ages with respect to diameter class. Among all but the largest trees, subalpine fir was consistently younger at a given diameter than the other three species. Among the smallest trees, the four species were clearly differentiated by age, with lodgepole the oldest and subalpine fir the youngest. These ages were a logical and inverse reflection of growth over a generally increasing period of time with increasing size, and suggested that among the smallest trees historical growth was greatest in subalpine fir and least in lodgepole pine. At the largest diameters a reverse pattern was evident among Engelmann spruce, whitebark pine, and lodgepole pine. This reverse pattern suggested that in the first years lodgepole pine grew the fastest and Engelmann spruce the slowest. Subalpine fir was anomalous, but was represented by very few large-diameter individuals.

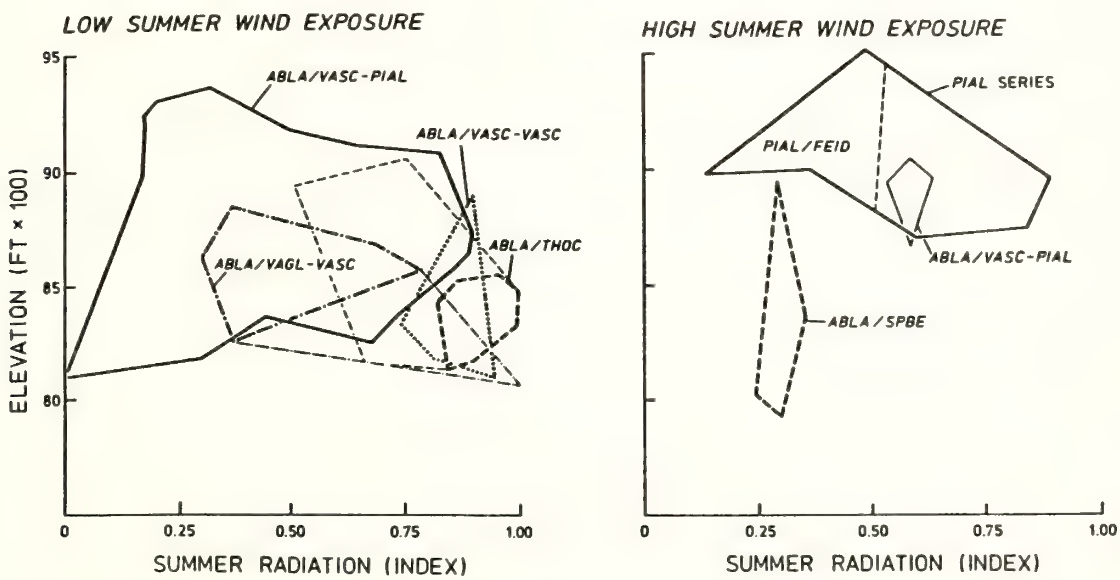

Figure 4—Distribution of habitat types with respect to summer radiation, elevation and summer wind exposure. Core and peripheral distributions of the Abla/Thoc and Abla/Vagl-Vasc types are denoted by thick and thin lines, respectively.

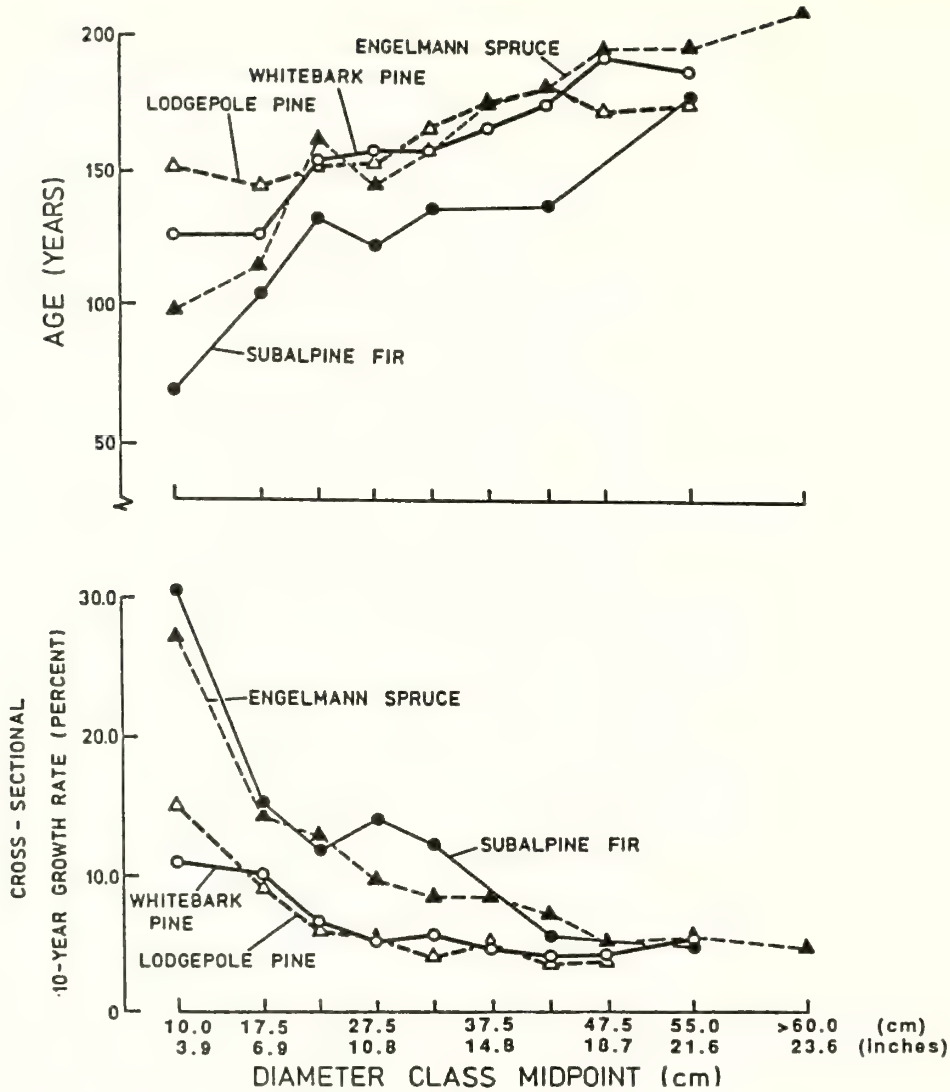

Figure 5—Mean age and cross-sectional growth rate of four major study area tree species with respect to diameter class.

Mortality and Stem Density of Whitebark Pine

Mortality of whitebark pine exhibited several patterns among size classes and habitat types (fig. 6). Averaged over all size classes, mortality was lowest in the PIAL series and highest on typically wet spruce-fir sites. In general, mortality rates irregularly decreased with increased stem diameter in all types. In the ABLA/VASC-PIAL and spruce-fir types, mortality peaked three times among small-, medium-, and large-diameter trees, respectively.

Stem densities and distribution of whitebark pine stems among size classes varied among types (fig. 6). Highest stem densities, especially among medium-diameter trees (5.9 to 15.7 inches d.b.h.), occurred in the PIAL series and ABLA/VASC-PIAL phase. Comparable densities of large-diameter (>15.7 inches d.b.h.) whitebark pine occurred in all of the types. Proportionately more small-diameter (<5.9 inches d.b.h.) stems occurred in, progressively, the PIAL series, ABLA/VASC-PIAL phase, mesic h.t.'s, and spruce-fir stands. By inference, proportionate recruitment of whitebark pine into the overstory also progressively increased in the same order among these types.

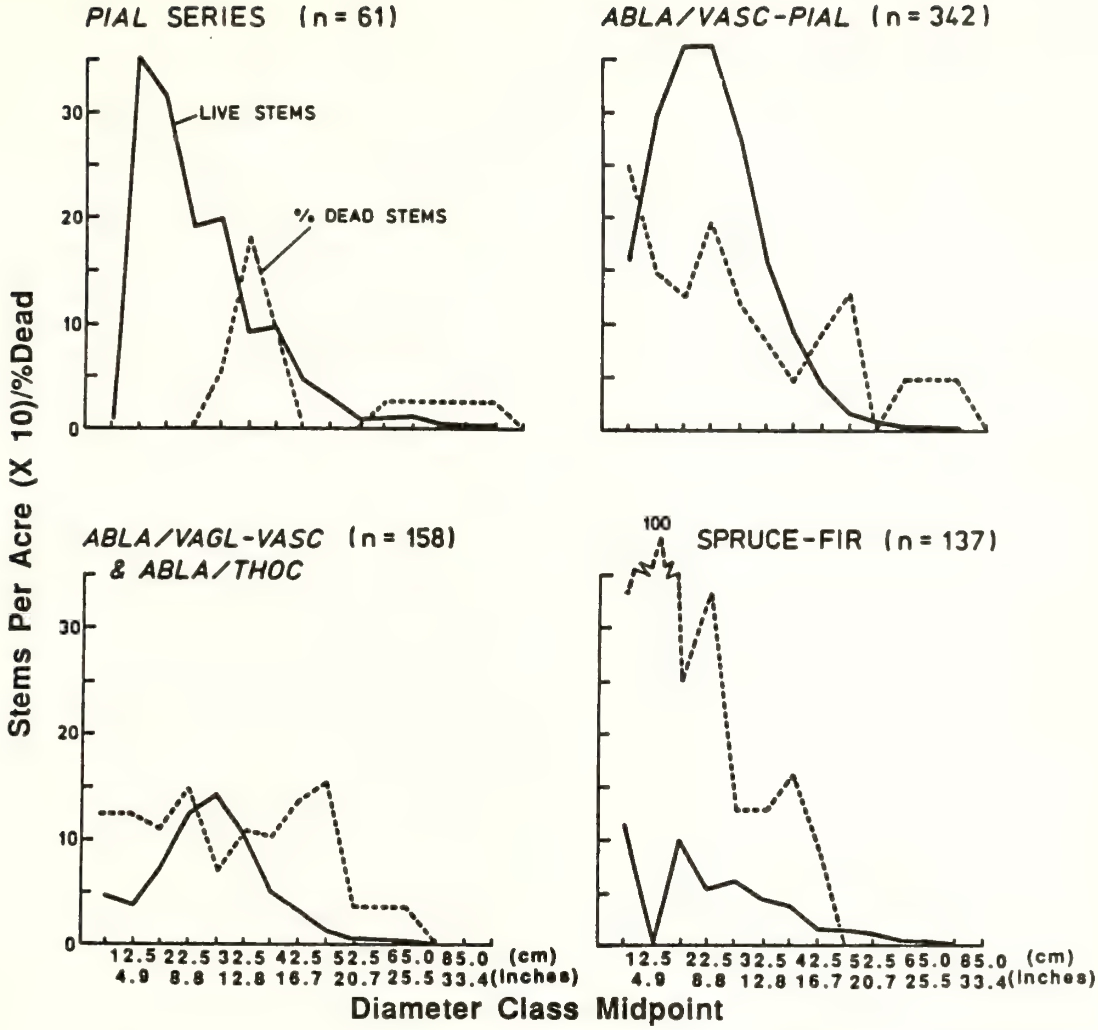

Figure 6—Mean stems per acre and percent dead stems of whitebark pine with respect to diameter class, for major study area cover and habitat types.

Basal Areas by Cover and Habitat Types

Average total basal area was relatively uniform for most habitat and cover types except for the PIAL series (table 1). In this series, total basal area was roughly one-half that of the other types, and consisted mostly of whitebark pine.

Whitebark pine basal area varied considerably among habitat and cover types (table 1). Whitebark pine basal area was typically highest in mid-successional cover types, and all cover types of the PIAL series and ABLA/VASC-PIAL phase. Lowest whitebark pine basal area occurred in spruce-fir cover types, and in the ABLA/THOC, ABLA/CACA, and ABLA/VASC-VASC types.

Stand Ages

Our study area included 82 stands approximately 150 to 310 years old (fig. 7). The majority of stands were between 180 and 270 years old. Roughly one-half of our study area burned in 1988.

We examined stand age distributions for the different successionally defined cover types (fig. 7). Although the late successional types (LP3 and WB3) included more older and fewer younger stands than the mid-successional types (LP2 and WB2), there was considerable overlap. The climax spruce-fir (SF) type also included a number of stands in the same age range as mid- and late-successional types, but typically included the oldest study area stands. Identification of the successional cover types of a stand in the whitebark pine zone is apparently more based on differences in stand species composition than on stand age.

Table 1—Total and whitebark pine basal area of habitat types and cover types of the Mount Washburn study area

Habitat type	Cover type	*n*	Basal area (ft²/acre) Total $\bar{X}$	Total S_x	Whitebark pine $\bar{X}$	Whitebark pine S_x	Whitebark pine Percent of total
PIAL series	WB2	3	106.7	—	83.6	—	78.0
	WB	4	98.0	34.0	84.9	35.7	86.0
ABLA/?[1]	WB3	4	134.1	39.2	64.0	22.2	48.0
ABLA/VASC-PIAL	WB2	6	186.8	34.0	121.5	39.2	65.0
	WB3	14	211.7	45.3	108.9	27.9	51.0
	LP2	3	210.8	—	28.7	—	14.0
	LP3	5	240.0	40.9	31.8	17.4	13.0
	SF	6	230.0	52.3	41.8	17.4	18.0
ABLA/VASC-VASC	LP2	5	219.5	34.8	9.6	5.7	4.5
ABLA/VAGL-VASC	LP3	6	191.2	20.5	42.7	32.2	22.0
	SF	2	220.8	—	4.4	—	2.0
ABLA/THOC	LP2	5	220.4	46.6	5.2	8.3	2.5
	LP3	4	211.2	36.6	19.6	24.0	9.0
ABLA/CACA	SF	3	239.1	—	25.7	—	11.0

[1]These stands could be a high-elevation variant of the ABLA/THOC h.t., but material identified as *Thalictrum occidentale* is in question and could be *T. fendleri*.

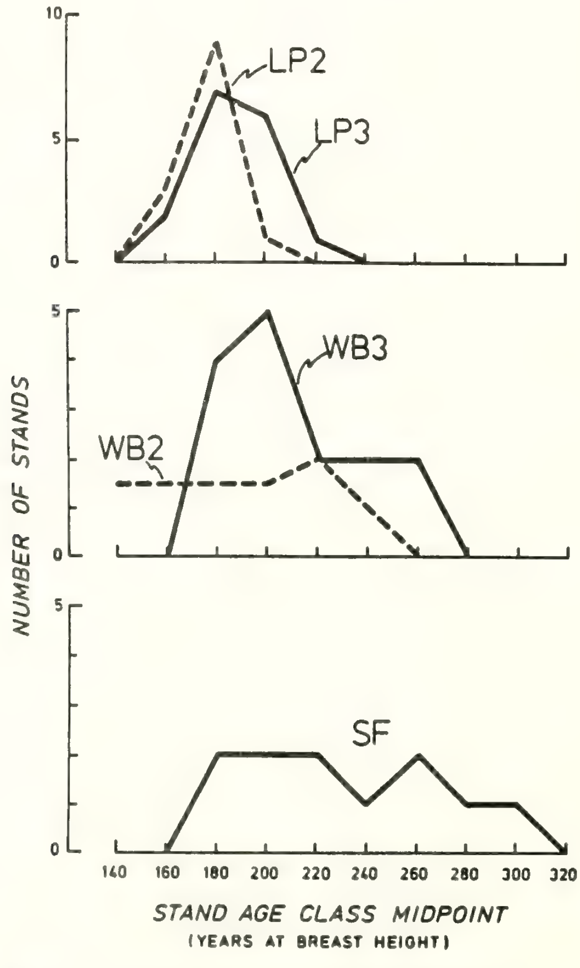

Figure 7—Frequency of stands with respect to stand age at breast height.

Tree Ages

We sampled individual tree ages on variable radius plots. For any given size class we sampled species relative to their proportionate representation. However, we sampled larger trees with proportionately much greater intensity than smaller trees. In figure 8 the relative pattern of species was significant, but absolute frequencies by age class merely reflected our sampling intensity.

We were able to assess two phenomena by species age-class frequencies in our study area (fig. 8): (1) relative rates of establishment after stand replacement and (2) approximate dates of stand replacement disturbances. The timing of peak frequencies for each species suggested that establishment and growth of whitebark pine to breast height (4 ft) lagged approximately 10 years behind that of lodgepole pine, and that establishment and growth of Engelmann spruce lagged 10 to 20 years behind that of whitebark pine. Subalpine fir patterns showed no easily identifiable relationship with the other species patterns, although there were proportionately more young subalpine fir compared to the other three species. Among the oldest stands, relative abundance of trees reversed from the order [lodgepole (1), whitebark pine (2), and Engelmann spruce (3)] characteristic of younger stands. From all tree ages we were also able to detect four stand-replacement fires in our study area (fig. 8). Using all tree ages, historic disturbances dated to approximately 1820, 1790, 1730 to 1760, and 1670.

DISCUSSION

The nature and limited geographic scope of our study imposed certain constraints on our analysis and conclusions. We did not sample young or very old stands. We were therefore unable to analyze growth of the tree species through time and address certain aspects of stand dynamics more definitively. We also did not include many stands on east and south aspects due to the location of our transects on primarily west exposures. South aspects, however, were characterized by a paucity of forest cover. We were also unable to take exhaustive age data due to study priorities and limited available time. However, within these constraints we were able to glean a considerable amount of valuable information from our data.

Whitebark Pine Autecology

Whitebark pine and lodgepole pine were distinguished from subalpine fir and Engelmann spruce by their greater occurrence on drier sites associated with increased wind exposure, that is, on sites with steeper slopes and higher mean summer windspeeds. We used summer rather than winter windspeeds in our analysis because of their stronger apparent relationship to tree species distributions in our study area. Whitebark pine was further distinguished from lodgepole pine by its greater apparent tolerance of cold, although not necessarily frosty, sites.

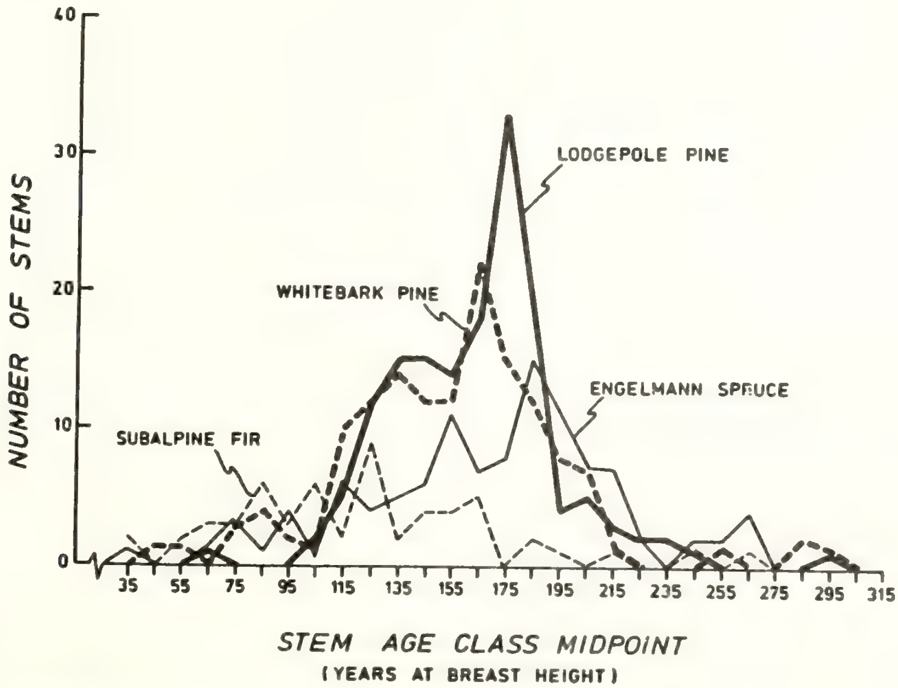

Figure 8—Frequency of stems with respect to stem age at breast height, for four major study area tree species.

With increasing elevation or colder exposures whitebark pine replaced lodgepole pine. The greatest rate of transition from whitebark to lodgepole pine occurred in association with the warmest sites of the whitebark pine zone. Subalpine fir and Engelmann spruce appeared to be less sensitive to site warmth, although abundance of subalpine fir declined and Engelmann spruce increased on the coldest sites.

Lodgepole pine and whitebark pine exhibited characteristics typical of early successional or relatively shade-intolerant species. Initial growth and establishment of both these species appeared to be greater than that of Engelmann spruce. In mid- to late-successional stages in our study area, general growth of the pines was slower than spruce and fir growth, although dominant large-diameter pines appeared to grow as well as comparable size spruce and fir. Differences in growth rates and apparent rates of establishment between lodgepole and whitebark pine could be attributed to differential distribution of whitebark pine on colder and presumably less productive sites, given that we agglomerated stands from the entire whitebark pine zone for our analysis of growth. On the other hand, slightly better apparent growth under closed-canopy conditions and lag in initial growth and establishment of whitebark pine compared to lodgepole pine could indicate greater shade tolerance—hence a tendency toward intermediate successional status for whitebark pine.

Arno and Habeck (1972) and Arno and Hoff (1989) ascribed greater shade tolerance to whitebark pine than to lodgepole pine. Similarly, Knowles and Grant (1983) considered the ecologically related limber pine (*Pinus flexilis*) to be intermediate in successional status between lodgepole pine and Engelmann spruce. Given this context, we suspect that our results are best interpreted as corroborating those earlier observations that whitebark pine is intermediate in shade tolerance between Engelmann spruce and lodgepole pine, although more similar in tolerance to lodgepole pine.

Sudworth (1967) commented that whitebark pine was more shade tolerant on deeper, moist soils at lower elevations than on drier, shallower soils near timberline. Greater environmental stress would logically impair the physiological efficiency of a species; in a tree this would very likely be manifested as a higher light compensation point (Kozlowski 1979; Kramer and Kozlowski 1960; Tranquillini 1979). Our results suggest that recruitment of whitebark pine into the overstory is proportionately least on the harshest sites of the Pial series and progressively greater with site amelioration; recruitment appears to be proportionately greatest on the mesic or lower elevation habitat types of the whitebark pine zones. These results corroborate the hypothesis that whitebark pine is more shade tolerant with site amelioration.

This tendency contrasts with the proclivity of whitebark pine to dominate a site. In our PIAL series, where whitebark pine is the climax dominant, whitebark does not appear to replace itself with great frequency. Other studies of near-pure stands of whitebark pine and ecologically related species—limber pine and Siberian stone pine (*Pinus sibirica*)—also show a lack of recruitment in mature stands (Iroshnikov and others 1963; Jackson and Fuller 1973; Knowles and Grant 1983). In the PIAL series, persistence of whitebark pine is probably dependent on stand gaps, widely dispersed in time and space, and on stand-replacement fires (Arno 1980; Fischer and Clayton 1983).

Our results suggest that lodgepole pine and whitebark pine are major competitors during early stages of stand development. Engelmann spruce also appears to be a major component of the initial stand, but at the same time appears to be more opportunistic and less competitive in these early stages. Whitebark pine has the apparent advantage over lodgepole pine on increasingly colder sites. We hypothesize that the absence of whitebark pine from forest overstories on warmer sites within the whitebark pine zone or at lower elevations is due largely to competitive exclusion, especially by lodgepole pine. Critchfield and Allenbaugh (1969) offered some anecdotal support for this hypothesis. At a latitude 3° farther south than our study area, they observed whitebark pine well represented as low as 6,400 ft in a mountain range without any other pine species. In two other mountain ranges at the same latitude, they observed whitebark pine to be common only down to 8,400-ft elevation, and replaced at lower elevations by limber pine. In our study area, whitebark pine is similarly well represented down to 8,200-ft elevation. In the absence of its other hypothesized major competitor, lodgepole pine, whitebark pine may very well be capable of attaining stand dominance on warmer sites.

Whitebark pine appears to be climax in a limited habitat characterized by high wind exposure and high elevations. Arno and Habeck (1972), Arno and Hoff (1989), Jackson and Fuller (1973), Steele and others (1983), and Sudworth (1967) also associated near-pure stands of whitebark pine with sites exposed to wind and sun. Climax subalpine limber pine stands in the Colorado Front Range are similarly associated with exposed drier sites (Peet 1981).

Climax status of whitebark pine appears to be by default. Whitebark pine apparently tolerates conditions associated with extreme wind exposure better than its competitors (Steele and others 1983), and is not climax in the classic sense of having greater shade tolerance (Emlen 1973:354). Stem frequencies of whitebark pine relative to diameter in the PIAL series do not exhibit the "inverse-J" pattern usually associated with a climax species (Whipple and Dix 1979). Basal area and overstory stem densities of whitebark pine are similar in the ABLA/VASC-PIAL phase and PIAL series. The two types are notably different by the absence of other tree species in the PIAL series. Whitebark pine, like lodgepole pine, appears to be climax because of its tolerance of extreme site conditions rather than competitive ability vis-a-vis other species under mature stand conditions (Despain 1983; Pfister and others 1977; Whipple and Dix 1979).

Stand Dynamics and Classification

Stand-replacement fires burned somewhere in our study area at relatively frequent, average 80-year, intervals. Given that virtually all our study area was burned at least once in a 300-year period and we found few 300-year-old stands, we speculate that our entire study area had a fire cycle of approximately 300 years' duration. This fits within the roughly 60- to 300-year fire frequency cycle documented for the whitebark pine zone by Arno (1980).

Our data suggest the prevalence of succession by "initial floristic composition" rather than "relay floristics" (Mueller-Dombois and Ellenberg 1974:395) in the tree strata of our study area. Subalpine fir increases markedly in the understory with stand age, but is represented at stand initiation, and rarely achieves stand dominance due to a prolonged seral stage relative to fire frequency. Relative composition of the overstory only begins to change markedly approximately 200 years after stand initiation.

Caution should be used when inferring successional status from cover type designations in the whitebark pine zone. Our classification of stands according to successional cover types was apparently determined as much by initial stand composition as by stand age (successional status). Stands classified as spruce-fir (SF) did not reflect progression to climax, but rather wetter or more protected sites and variants of habitat types where initial establishment of spruce and fir was favored. Similarly, some stands classified as mid-successional WB2 types merely reflected conditions where establishment of whitebark pine was favored over sites with comparably aged stands classified as late-successional WB3 types. These aberrations reflect the persistent expression of initial floristic composition in stands of a zone where growth and turnover of individuals are relatively slow.

THE FUTURE

Much of the discussion presented here is speculative. Researchers have enough collective information at this point to generate well-founded hypotheses, but few definitive studies to test them and, from their conclusions, to direct management. To further test our hypotheses and speculations, we especially need comparative physiological studies that deal with whitebark pine and its potential competitors and survey studies that can provide additional data for modeling efforts. Our future management of whitebark pine and its seed crops for a host of vertebrate species will only be as good as our understanding of its habitat and competitive relationships.

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APPENDIX A—HABITAT TYPE NOMENCLATURE AND ACRONYMS (STEELE AND OTHERS 1983; THIS STUDY)

Acronym	Common name	Scientific name
PIAL series	Whitebark pine series	*Pinus albicaulis* series
PIAL/FEID h.t.	Whitebark pine/Idaho fescue h.t.	*P. albicaulis/Festuca idahoensis* h.t.
PIAL/THFE h.t.	Whitebark pine/Fendler's meadowrue h.t.	*P. albicaulis/Thalictrum fendleri* h.t.
ABLA/VASC-PIAL phase	Subalpine fir/grouse whortleberry-whitebark pine phase	*Abies lasiocarpa/Vaccinium scoparium-P. albicaulis* phase
ABLA/VASC-VASC phase	Subalpine fir/grouse whortleberry-grouse whortleberry phase	*A. lasiocarpa/V. scoparium-V. scoparium* phase
ABLA/VAGL-VASC phase	Subalpine fir/globe huckleberry-grouse whortleberry phase	*A. lasiocarpa/V. globulare-V. scoparium* phase
ABLA/THOC h.t.	Subalpine fir/western meadowrue h.t.	*A. lasiocarpa/Thalictrum occidentale* h.t.
ABLA/SPBE h.t.	Subalpine fir/shiny-leaf spiraea h.t.	*A. lasiocarpa/Spiraea betulifolia* h.t.

Lodgepole Pine Types

COVER TYPE—30 (LP0)

Recently burned or harvested lodgepole pine stands in the grass to seedling/sapling stage before canopy closure. Approximately 0-40 years postfire.

COVER TYPE—31 (LP1)

Closed canopy of even-aged, usually dense, lodgepole pine where trees are younger and shorter than those of neighboring stands. Young pole successional stage. On outwash at West Yellowstone, it is represented by islands of scattered short trees next to islands of scattered larger trees. Approximately 40-100 years postfire.

COVER TYPE—32 (LP2)

Closed canopy dominated by lodgepole pine. Overstory still largely intact. Mature lodgepole pine successional stage. Understory usually small to medium Engelmann spruce and subalpine fir seedlings and saplings but also may be mostly lodgepole pine. Approximately 100-300 years postfire.

COVER TYPE—33 (LP3)

Canopy quite ragged, predominately of overmature lodgepole pine but containing some Engelmann spruce, subalpine fir, and whitebark pine in the pole-sized class. Old-growth lodgepole pine successional stage. Understory of small to large spruce and fir seedlings and saplings. Three hundred plus years postfire.

COVER TYPE—34 (LP)

Canopy dominated by overmature lodgepole pine beginning to break up. Understory of lodgepole pine and whitebark pine. Stands usually on rhyolite and multiaged. Lodgepole is climax or persistent seral species. Three hundred plus years postfire.

Whitebark Pine Types

COVER TYPE—50 (WB0)

Recently burned whitebark pine stands usually near upper timberline where whitebark pine clearly dominates reproduction.

COVER TYPE—51 (WB1)

Even-aged, closed whitebark pine stands where trees are younger and shorter than those of neighboring stands. Trees are small pole sized.

COVER TYPE—52 (WB2)

Closed canopy dominated by whitebark pine. Overstory still largely intact. Trees pole to mature sized. Understory usually small to medium Engelmann spruce and subalpine fir seedlings and saplings but may be mostly whitebark pine. Approximately 100-300 years postfire.

COVER TYPE—53 (WB3)

Stands dominated by mature whitebark pine and may also contain considerable Engelmann spruce, subalpine fire, or lodgepole pine. Understory is a combination of Engelmann spruce, subalpine fir, and whitebark pine.

COVER TYPE—54 (WB)

Stands of mature to overmature whitebark pine where the reproduction is nearly all whitebark pine.

COEVOLUTION OF WHITEBARK PINE AND NUTCRACKERS: IMPLICATIONS FOR FOREST REGENERATION

Diana F. Tomback
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ABSTRACT

Clark's nutcracker (Nucifraga columbiana) *is the primary disperser of the large, wingless seeds of whitebark pine* (Pinus albicaulis). *The seed-storing habits of nutcrackers influence whitebark pine distribution, site preference, and population structure. In the northern Rocky Mountains, periodic fires followed by seed dispersal by nutcrackers regenerate seral whitebark pine communities. Data from two burns in the Bitterroot National Forest, Montana, show similar whitebark pine regeneration patterns and densities but different subalpine fir densities. Seed dispersal by nutcrackers may give whitebark pine a competitive edge over subalpine fir in very large burns, particularly where wind patterns are unfavorable for subalpine fir seed dispersal.*

INTRODUCTION

The seeds of most conifers are disseminated by wind, but the large, wingless seeds of whitebark pine (*Pinus albicaulis* Engelm.) are disseminated primarily by Clark's nutcracker (*Nucifraga columbiana* Wilson) (Hutchins and Lanner 1982; Tomback 1978, 1982). Dispersal is effected by the seed-storing habits of the bird, which profoundly influence many aspects of the biology of the pine. In this paper we briefly review salient features of the ecological interaction between whitebark pine and the nutcracker, emphasizing the role of the nutcracker in forest regeneration. We also illustrate the importance of seed dispersal by nutcrackers in maintaining seral whitebark pine communities in the northern Rocky Mountains with recent data on postfire forest regeneration in the Bitterroot National Forest of western Montana.

THE NUTCRACKER-PINE INTERACTION

Eight of the 100 or so pine species are known to be dispersed by two birds of the family Corvidae, the Clark's nutcracker of western North America and the Eurasian nutcracker (*N. caryocatactes* [L.]) of Europe and Asia. The known nutcracker-dependent pines of the United States are the Colorado pinyon (*P. edulis* Engelm.) and the singleleaf pinyon (*P. monophylla* Torr. and Frem.) (Vander Wall and Balda 1977; Vander Wall 1987), whose seeds also are dispersed by the pinyon jay (*Gymnorhinus cyanocephalus* Weid) (Ligon 1978; Vander Wall 1987), limber pine (*P. flexilis* James) (Lanner and Vander Wall 1980), and whitebark pine (Hutchins and Lanner 1982; Tomback 1978, 1981, 1982). Dependence on birds for seed dispersal apparently has resulted in character convergence among pines of different taxonomic affinities; all have large, wingless seeds and, with the exception of limber pine, seed retention in cones (Lanner 1980, 1982; Tomback 1983). In the pinyon pines, seeds are held in place by bracts in dehisced cones; in whitebark pine, the ripe cones are indehiscent. Because large, wingless seeds and seed retention increase foraging efficiency of nutcrackers, the birds first deplete seeds from pines with these traits before moving to sympatric wind-dispersed species (Tomback 1978; Vander Wall and Balda 1977; but see Tomback and Linhart 1990).

The nutcrackers are also morphologically adapted to the interaction. Their sturdy, long, pointed bills are used to open pine cones and extract seeds (Tomback 1978; Vander Wall and Balda 1977). They also use their bills to dig sites for seeds in mineral soil; and they thrust seeds into place in sandy soil or loose substrates (Tomback 1978). By means of the sublingual pouch, a saclike extension of the floor of the mouth (Bock and others 1973), a nutcracker may transport up to 150 whitebark pine seeds at a time (Tomback 1982). Each nutcracker recovers its own seed stores by means of a remarkable spatial memory (Kamil and Balda 1985; Tomback 1980; Vander Wall 1982).

The historical origin of nutcracker-dispersed pines, previously discussed by Lanner (1980), Tomback (1983), and Tomback and Linhart (1990), is briefly summarized here. Whitebark pine is the only North American pine in the subsection Cembrae (Critchfield and Little 1966). The other four Cembrae pines, the stone pines of Europe and Asia, depend on the Eurasian nutcracker for seed dispersal (Turcek and Kelso 1968). *Nucifraga* and Cembrae pines probably coevolved in Eurasia, and forms ancestral to Clark's nutcracker and the whitebark pine crossed the Bering Strait land bridge into North America (Lanner 1980; Turcek and Kelso 1968). In North America, seed-storing jays probably influenced the evolution of limber pine (Lanner 1980) and the pinyon pines (Tomback 1983).

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As a consequence of range expansion by either the birds or the pines, nutcrackers found these pines to be attractive food sources. If this sequence of events is correct, the relationship between the Clark's nutcracker and whitebark pine was coevolved; the relationship with the other New World wingless-seed pines was initially coadapted (based on adaptations evolved for other mutualists) (Tomback 1983).

Assuming that seed dispersal by wind is an ancestral state, Lanner (1980) suggested a connection among seed dispersal by birds, wingless seeds, xeric or high-elevation environment, and large seed size. Large seed size under stressful conditions allows rapid, early growth (Baker 1972). It is possible that ancestral pines encountered rigorous semiarid and subalpine environments, either by climatic change or by range expansion, and evolved larger seeds. This, in turn, decreased the effectiveness of anemochory and attracted seed-storing jays or nutcrackers (Tomback 1983). If the sites selected by the birds were incompatible with the germination and growth requirements of a pine, the pines could not evolve bird-dependence. However, if the sites were compatible with some genotypes, seed wings might decrease in size and bird-dependency evolve (Tomback 1983). This evolutionary scenario and proposed genetic mechanisms are discussed at length in Tomback and Linhart (1990). Why winglessness and bird-dependency are not as prevalent in the pine subgenus *Pinus* (yellow or hard pines) as they are in the subgenus *Strobus* (white or soft pines) remains unclear.

SEED DISPERSAL BY NUTCRACKERS

Nutcrackers have a year-round diet of fresh and stored pine seeds, supplemented by insects and various plant foods (Giuntoli and Mewaldt 1978; Tomback 1978). Stored seeds are used during winter and spring months when other foods are scarce (Tomback 1978) and are fed, almost exclusively, to nestlings and dependent juveniles (Mewaldt 1956; Tomback 1978; Vander Wall and Hutchins 1983).

With respect to quantities of seeds dispersed and the burial of seeds at cache sites, nutcrackers are highly efficient seed dispersers. In late summer and fall, a single nutcracker may store between 32,000 (Tomback 1982) and 98,000 (Hutchins and Lanner 1982) whitebark pine seeds. Seeds are buried under 1 to 3 cm of soil in clusters of 1 to 15 seeds with a mean of 3 or 4 seeds per site (table 1). Tomback (1982) estimated that a population of 25 nutcrackers stored about 800,000 seeds within a

Table 1—Cache and cache site characteristics of Clark's nutcracker. Modified from Tomback and Linhart (1990)

Characteristic			**Characteristic**		
No. of seeds per cache			**Characteristics of storage slopes**		
$\bar{X}$	**S.D.**	**Range**	**Exposure**	**Slope**	**Substrate**
3.7	2.9	1-15 (a)	SE,S,SW,WSW	22-30°	pumice or gravel (f)
3.2	2.8	1-14 (b)	southern	25-33°	loose gravel (e)
4.2	3.1	1-5 (c)	**Microhabitats of cache sites**		
4.0	2.7	1-14 (d)	Base of trees or under canopy, near logs, in small plants, open substrate. (b,e,f)		
Cache depth (cm)			Forest litter, among tree roots, in trees. (f)		
$\bar{X}$	**Range**				
2.0	1-3 (a)		In moss. (b)		
about	2-3 (b)		Barren ledges and fissures on rock walls. (g)		
Distance seeds transported (km)					
7.5, 22 (e)			In forest floor of burned and live krummholz pine. (h)		
2.5, 4.5, 8-10, 12.5 (f)					
3.5 (b)			Steep slopes among rocks and vegetation, and cracks in granite (ESE,NW). At edges of meadows among grasses, sedges and rocks. (i)		

Reference	***Pinus***	**Geographical location**
(a) Tomback (1982)	*albicaulis*	eastern California
(b) Hutchins and Lanner (1982)	*albicaulis*	western Wyoming
(c) Lanner and Vander Wall (1980)	*flexilis*	northwestern Utah
(d) Vander Wall and Balda (1981)	*edulis*	northern Arizona
(e) Vander Wall and Balda (1977)	*edulis*	northern Arizona
(f) Tomback (1978)	*albicaulis*	eastern California
(g) Tomback and Kramer (1980)	*flexilis*	eastern California
(h) Tomback (1986)	*albicaulis*	eastern California
(i) Tomback and Knowles (1984)	*albicaulis*	western Wyoming

50-ha area (16,000 seeds/ha) in the California Sierra Nevada range. Vander Wall and Balda (1977) estimated that a population of 150 nutcrackers stored between 3 and 5 million Colorado pinyon seeds in their San Francisco Mountains study area in northern Arizona. According to calculations by Vander Wall and Balda (1977) and Tomback (1982), the number of seeds stored per bird represents several times its energy requirements during the period the seeds are used.

Nutcrackers may bury caches near parent trees, or they may travel distances of a few to 22 km (table 1), often with substantial changes in elevation (Tomback 1978; Vander Wall and Balda 1977). The sites selected for seed storage are on forest floor, above treeline, on rocky outcrops, in meadow edges, in clearcuts, and in burns. Often, a steep, south-facing slope may be used by a local population of birds (table 1). Seed storage in south-aspect or wind-blown sites probably ensures that some caches are snow-free in winter and spring. Placement of caches at different elevations relates to later seasonal altitudinal movements (Tomback 1978). Caches not recovered by nutcrackers may germinate in spring and summer, producing clusters of seedlings (Tomback 1982).

The seed shadow (seed dispersal pattern) of a wind-dispersed conifer typically conforms to a negative exponential distribution; most seeds land within 20 to 50 m of the parent tree, and few seeds travel beyond 60 to 250 m (McCaughey and others 1986). The seed shadow of whitebark pine may also resemble a negative exponential distribution (Sund 1988; Sund and others 1989; Tomback and others 1989a), but because of the distances that nutcrackers travel and the variety of sites used for seed storage, the seed shadow is far more extensive and unpredictable than that of wind-dispersed conifers (Tomback and Linhart 1990). One nutcracker may disperse seeds from one stand of trees to different areas. Within these areas, more than one nutcracker may store seeds, each bird with seeds from a different stand of trees. Nutcrackers may disperse seeds far from other trees, resulting in "outlying" individuals and a pioneering status for whitebark pine. In addition, by caching seeds at high elevations, nutcrackers may maintain timberline at the highest climatic limits for whitebark pine (Mattes 1982; Tranquillini 1979).

POPULATION STRUCTURE OF WHITEBARK PINE

The population structure of whitebark pine differs in many respects from that of wind-dispersed conifers, because of the foraging and caching behaviors of nutcrackers. First of all, whitebark pine, limber pine, and Swiss stone pine (*P. cembra* L.) are known to grow in a "multi-trunk" form (Clausen 1965; Holtmeier 1988; Lanner 1980). This form appears to be a single tree with two or more trunks sometimes fused at or above the base. The frequency of occurrence of this growth form and mean number of trunks per tree vary geographically (table 4 in Tomback and Linhart 1990). Protein electrophoresis confirms that most of these multi-trunk trees contain two or more distinct genotypes (Furnier and others 1987; Linhart and Tomback 1985; Tomback and others 1989b); this supports the suggestion by Lanner (1980) that each trunk of a multi-trunk tree may originate from one seed of a multi-seed nutcracker cache. The consequence of this growth form is an extremely clumped population dispersion pattern (individuals often occur in small clumps).

To complicate matters, not all multi-trunk trees consist of more than one genotype. For one of the six (17 percent) multi-trunk whitebark pine trees analyzed by Linhart and Tomback (1985) and 12 of 35 (34 percent) analyzed by Furnier and others (1987), only one genotype per tree was found. Perhaps if they had examined more gene loci, additional distinct genotypes would be identified; however, it is more likely that some multi-trunk trees were of only one genotype. This possibility was recently discussed for a disjunct population of limber pine in which 88 of 106 (83 percent) multi-trunk trees consisted of one genotype (Schuster and Mitton 1988). In most cases, there were no aboveground morphological clues to the origin of the growth form. Schuster and Mitton (1988) suggested that damage to the leader shoot may result in the growth of side branches into main trunks and also that some individuals may have a genetic predisposition for release from apical dominance. Both effects may vary with biotic and abiotic conditions. Consequently, the genetic makeup of multi-trunk trees cannot be assumed without genetic analysis.

The complexities of growth form in whitebark and limber pine necessitate clear terminology in discussions. We propose the following: single-trunk tree (typical of conifers), multi-trunk tree (single genotype), and tree cluster (multiple genotypes). If the genetic makeup of a tree is unknown and such information is relevant, the point should be clearly stated. For example, the tree might be described as a multi-trunk tree of unknown genetic composition or of unknown origin.

In addition, the genetic relationships among individuals within a tree cluster differ from those between tree clusters, because nutcrackers usually harvest a number of seeds from the same parent tree. Tomback (1988a) estimated that 73 to 93 percent of caches contain two or more sibling or half-sibling seeds, and caches usually contain a mix of related and nonrelated seeds. Electrophoretic analysis indicated that individual whitebark pine trees in a cluster were genetically more similar to each other than to trees in nearby clusters (Furnier and others 1987). This finding was confirmed for limber pine as well by Schuster and Mitton (1988).

Furthermore, because more than one nutcracker may cache seeds in a given area (Tomback 1978), and each nutcracker may harvest seeds from different stands, the genetic structure among tree clusters may be randomized (Furnier and others 1987; Tomback and Linhart 1990). In fact, Furnier and others (1987) did not find a family structure (a relationship between genotype and distance) similar to that of wind-dispersed conifers among tree clusters in two whitebark pine stands, nor did Schuster and Mitton (1989) find a family structure within several limber pine populations. The family structure of wind-dispersed conifer populations comes from shorter, more predictable seed dispersal distances (Knowles 1984; Linhart 1989; Linhart and others 1981).

ROLE OF NUTCRACKERS IN FOREST REGENERATION

Climax Communities, Primary and Secondary Succession

Climax communities are relatively open and favorable to establishment of the moderately shade-tolerant whitebark pine (Arno and Hoff 1989). By caching seeds in forested sites (Tomback 1978), nutcrackers maintain climax communities of whitebark pine. In some montane regions, such as the Sierra Nevada, most of the whitebark pine occurs in climax stands at subalpine and treeline elevations. Fire is of limited importance, typically consuming less than 0.5 ha of forest per burn (Tomback 1986). In the northern Rocky Mountains where fire is more important, whitebark pine alone or with subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.) and Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) forms climax communities at treeline elevations and on exposed subalpine sites (Arno and Hoff 1989).

The tendency of nutcrackers to disperse seeds at a distance from parent trees indicates that whitebark pine may become established in new environments as they arise. Examples include the invasion of the shores of subalpine lakes when water levels decrease and the invasion of subalpine meadows (Dunwiddie 1977). An unusual example involves the Swiss stone pine. The Morteratsch Glacier of the Engadine Valley of Switzerland has retreated about 1 km since 1900 and, on the exposed, bare lateral morraines, Swiss stone pines are already established (Tomback 1988b). This is an illustration of primary succession, according to some definitions (Smith 1986), initiated by a bird.

Nutcrackers are attracted to open sites for seed caching and will fly great distances to use them (Tomback 1978). McCaughey (1987) observed nutcrackers caching quantities of whitebark pine seeds in a recent clearcut. Studies of regeneration following fire indicate the efficacy of nutcrackers in seeding burns, even areas several kilometers from a seed source (Sund 1988; Sund and others 1989; Tomback 1986; Tomback and others 1989a).

Examples of Postfire Regeneration

Alpine Timberline: Cathedral Peak, Yosemite National Park—On exposed, high-elevation sites, whitebark pine assumes a shrublike or elfinwood growth form (Clausen 1965) sometimes referred to as krummholz. In 1975, a lightning strike ignited a fire on the west slope of Cathedral Peak, Yosemite National Park, elevation 3,337 m, that severely burned 2 ha of a krummholz whitebark pine stand. In 1979, regeneration was surveyed along a series of 2-m belt transects totalling 790 m in length and representing about 8 percent of the area of the burn (Tomback 1986). The density of seedling sites per transect ranged from $0.015/m^2$ to $0.027/m^2$ with an overall density of $0.020/m^2$. At each regeneration site there were one to four seedlings (from germination of seeds within a nutcracker cache) with a mean of 2.6 (S.D. = 0.74). Tomback (1986) observed nutcrackers transporting whitebark pine seeds up from cone-bearing stands of erect trees on the lower west and east slopes and caching them in the burn.

Because krummholz conifer forms typically produce few cones and the seeds have low germination capacity (Tranquillini 1979), it is likely that most of the seedlings in the burn originated from trees of the erect growth form from lower elevations (Tomback 1986). Assuming that this is true, the question remains whether the regenerating trees will be krummholz in form, and, if so, whether they will be genetically differentiated by selection from the populations of parent trees or whether the krummholz growth form is primarily the product of the severe environment. Previous studies of Engelmann spruce and subalpine fir show differences in peroxidase proteins between the krummholz and erect tree forms (Grant and Mitton 1977).

Seral Whitebark Pine Community: Bitterroot National Forest—Throughout the Northern Rocky Mountains, periodic fire followed by seed dispersal by nutcrackers historically renewed seral whitebark pine communities; however, the fire suppression practices of the last 80 years have lengthened the interval between fires (Arno 1980, 1986). In the absence of fire, shade-tolerant subalpine fir, sometimes in combination with Engelmann spruce or mountain hemlock (*Tsuga mertensiana* [Bong.] Carr.), replaces whitebark pine (Arno 1986; Arno and Hoff 1989). Because of diminishing whitebark pine populations, the status of whitebark pine in several large-scale burns is currently of concern.

CASE STUDIES: THE SLEEPING CHILD BURN AND SADDLE MOUNTAIN BURN

In 1987 and 1988, we examined forest regeneration in the Sleeping Child and Saddle Mountain Burns, respectively, Ravalli County, Bitterroot National Forest, western Montana. The primary elevational range for whitebark pine in this region is 2,290 to 2,620 m (Arno and Hoff 1989; Pfister and others 1977). At lower subalpine elevations (2,130 to 2,290 m), occasional islands of whitebark pine occur on exposed or rocky areas. Forest regeneration patterns observed in the Sleeping Child Burn were compared with patterns in the Saddle Mountain Burn. The two study areas were selected for similarities in time elapsed since fire, severity of the fire, and the relationship between whitebark pine seed source and topography. Details concerning the studies are reported elsewhere (Sund 1988; Sund and others 1989; Tomback and others 1989a).

Study Areas

The Sleeping Child Burn resulted from an uncontrollable lightning-ignited fire in 1961 that consumed about 11,350 ha of forest on the west slope of the Sapphire Range (fig. 1). Fuel accumulation from a mountain pine beetle (*Dendroctonus ponderosae* Hopk.) epidemic in the 1930's contributed to the severity of the burn (Lotan 1976). Lodgepole pine (*Pinus contorta* Dougl.) dominated the lower subalpine at the time of the fire (Lotan 1976; Lyon and Stickney 1976).

Figure 1—Sleeping Child Burn, Bitterroot National Forest, western Montana. View toward the west along the ridge study area.

The primary whitebark pine seed source is continuous stands of mature trees at elevations above 2,250 m on the northeastern edge of the burn. In these stands, subalpine fir, Engelmann spruce, and lodgepole pine also provide seed sources for regeneration. Analysis of two plots in these stands indicated that whitebark pine and subalpine fir were the most common species (Sund 1988; Sund and others 1989). Potential seed sources for subalpine fir, spruce, and lodgepole pine also occur on the other perimeters of the burn and on small forest islands in the burn.

The principal study area was a 3.7-km long ridge that is contiguous with the unburned forest on the east edge and extends nearly due west into the northern center of the burn (fig. 2). Elevation along the ridge decreases from 2,482 m to 2,173 m with increasing distance from the edge of the burn. A second study area, following the Skalkaho-Rye Creek Road and then Paint Creek Road south through the center of the burn (fig. 2), was selected to measure regeneration at distances up to 8 km from the whitebark pine seed source and at elevations as low as 2,100 m.

The Saddle Mountain Burn, in the Bitterroot Mountains near Lost Trail Pass, resulted from an uncontrollable lightning-strike fire in 1960 that destroyed about 1,240 ha of forest (fig. 3). Running northeast to southwest in the longest dimension, the burn ranges from about 2,475 m to 1,950 m elevation (fig. 4). Relatively flat in profile, the northeastern 2 km of the burn fluctuate around 2,100 m elevation, with a hill near the northeast end. The southwestern 1.2 km of the burn increase steeply in elevation (fig. 4). The whitebark pine seed source is at the southwest edge of the burn above 2,250 m elevation in stands where whitebark pine and subalpine fir are equally common and lodgepole pine and Engelmann spruce are present in small numbers (Tomback and others 1989a). Additional seed sources for lodgepole pine, spruce, subalpine fir, and Douglas-fir (*Pseudotsuga menziesii* [Beissn.] Franco) occur within about 0.5 km of the lower perimeter.

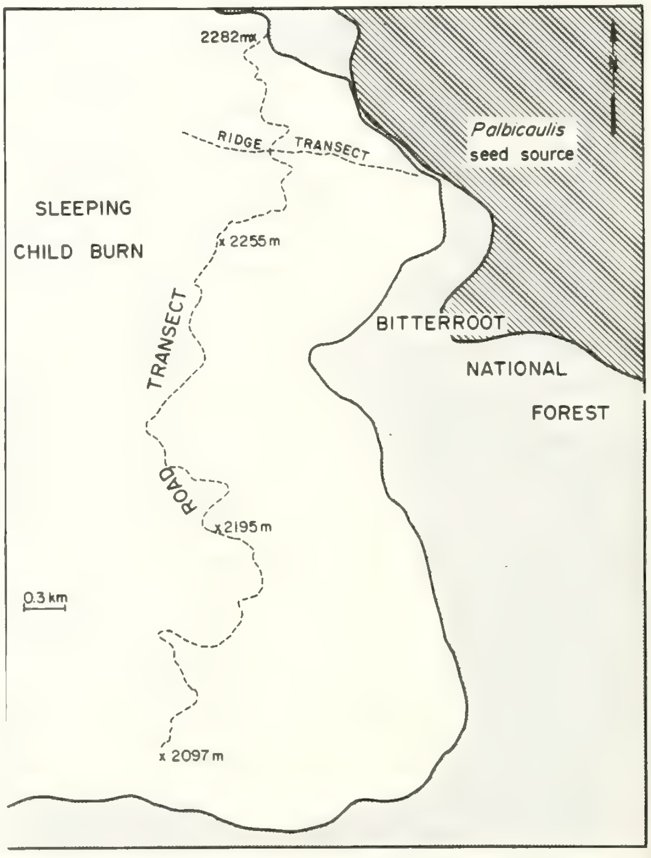

Figure 2—Sleeping Child Burn: ridge and road study areas. The dark, striped area indicates forest above 2,250 m elevation where continuous stands of whitebark pine provide the seed source for regeneration.

Figure 3—Saddle Mountain Burn, Bitterroot National Forest, western Montana. View toward the southwest end of the study area.

Methods

In the Sleeping Child Burn, fieldwork was conducted from August 3 to 26, 1987. On the ridge study area, plots were established every 150 m along a 3.6-km transect beginning 50 m from the whitebark pine seed source. For each ridge plot, a plot on the south and north aspects of the ridge was also established to compare the influence of aspect on regeneration abundance. Altogether, 63 plots were studied: 21 north, 19 south, and 23 ridge. The plot sizes ranged in set increments from 50 by 1.25 m to 50 by 12 m with respect to local densities of whitebark pine (for details, see Sund 1988; Sund and others 1989). Along the road transect 14 plots, 30 by 1.5 m to 30 by 10 m in area, were established on suitable north aspect sites. The plots ranged from 0.9 to 8 km from the whitebark pine seed source.

We sampled regeneration in the Saddle Mountain Burn from August 1 to 9, 1988. Two parallel transects A and B, separated by 10 m, began at the steep, southwest edge of the burn and continued 3.2 km northeast (fig. 4). On the steep part of the burn, plots were established every 100 m along each transect for a total of 16 plots. On the flat part of the burn, plots were established every 50 m along transect A, for a total of 15 plots, but every 100 m along the B transect for a total of 10 plots. All 41 plots were 50 m long with belt widths up to 20 m (for details, see Tomback and others 1989a).

For both burns, plot measurements included elevation, aspect, slope angle, and distance from the whitebark pine seed source. All seedlings and trees on the plots were counted. "Regeneration site" refers to the location on a plot of a seedling or tree. For whitebark pine, a single regeneration site might represent more than one seedling or tree. In such cases, cluster size was determined by separating stems or trunks at or below ground level. All whitebark pine seedlings or trees were aged in the Sleeping Child Burn, and representatives of different height classes were aged in the Saddle Mountain Burn. In both areas, representatives of height classes for the other conifer species were also aged (for details, see Sund 1988; Sund and others 1989; Tomback and others 1989a).

Results and Discussion

In the Sleeping Child Burn, a total of 455 whitebark pine, 60 subalpine fir, 37 Engelmann spruce, and 436 lodgepole pine trees were encountered in the ridge area study plots (table 2). At 48 percent (217) of the whitebark pine sites, seedlings or trees occurred in clusters of 2 to 8, with a mean of 1.91. The oldest trees (total age) recorded

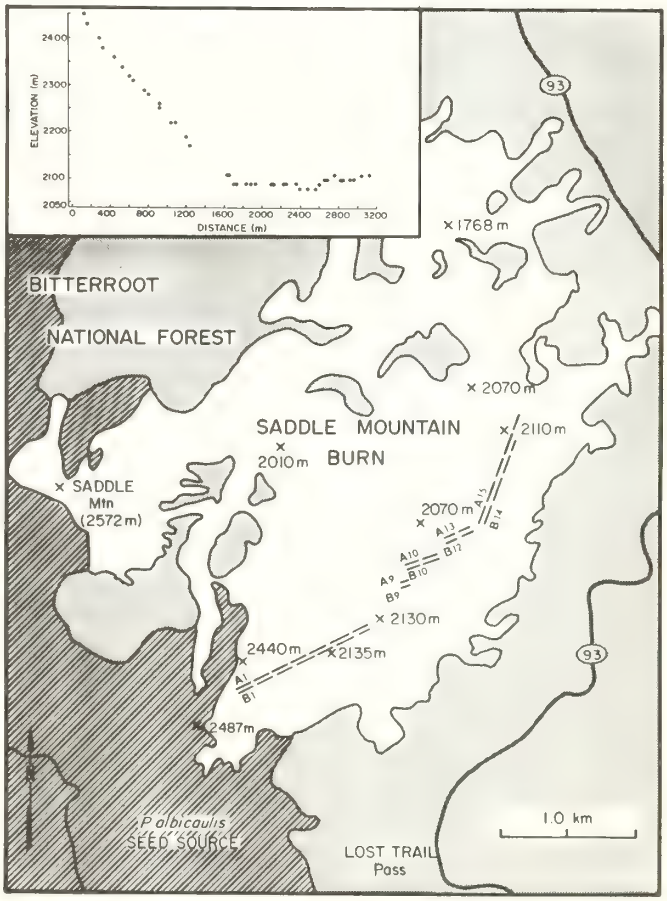

Figure 4—Saddle Mountain Burn. Path of parallel A and B transects through the burn. The dark, striped area indicates forest above 2,250 m where continuous stands of whitebark pine provide the seed source for regeneration. The stippled area indicates unburned forest around the perimeter of the burn. On the inset graph of elevation versus aerial distance from the whitebark pine seed source, each point represents a single study plot ($n = 41$).

Table 2—Sample sizes and 1987 conifer regeneration densities for three series of plots on the ridge study area in the Sleeping Child Burn

	Plot series			
	North	Ridge	South	Total
No. plots	21	23	19	63
No. regeneration sites				
whitebark pine	271	119	65	455
subalpine fir	33	21	6	60
Engelmann spruce	19	16	2	37
lodgepole pine	115	186	135	436
Area sampled (m^2)				
whitebark pine	3,500	5,750	6,225	15,475
others	3,250	4,625	4,350	12,225
Plot densities (sites/m^2)				
Range				
whitebark pine	0.006-.512	0.000-.192	0.001-.110	0.000-.512
subalpine fir	.000-.080	.000-.032	.000-.032	.000-.080
Engelmann spruce	.000-.024	.000-.056	.000-.008	.000-.056
lodgepole pine	.000-.176	.000-.296	.000-.296	.000-.296
Mean, standard deviation				
whitebark pine	0.140,.145	0.044,.060	0.025,.032	0.070,.104
subalpine fir	.014,.019	.006,.010	.002,.008	.008,.001
Engelmann spruce	.006,.008	.004,.012	.001,.002	.004,.009
lodgepole pine	.031,.046	.051,.080	.036,.069	.040,.066

for each species were 21 years for whitebark pine, 24 years for fir and lodgepole pine, and 20 years for spruce. Regeneration apparently began soon after the burn, because at the time of sampling 26 years had elapsed since the fire. On the north aspect plot series, whitebark pine had the highest plot density and mean plot density of all conifers on the three plot series, 0.512 sites/m^2 and 0.140 sites/m^2, respectively (table 2). The high density on this aspect may result from either nutcracker caching preferences or environmental conditions. In fact, whitebark pine prefers moister areas in the more arid montane regions (Arno and Hoff 1989). The highest mean fir and spruce plot densities also occurred on the north aspect, but the highest mean lodgepole pine plot density occurred on the ridge (table 2). Whitebark pine and lodgepole pine had similarly high mean densities on the ridge and south plot series. Mean densities for all three plot series combined indicated the following density ranking, from highest to lowest: whitebark pine, lodgepole pine, fir, and spruce. Because sampling areas differed among the conifer species, statistical comparisons are of limited value.

On the road study area, whitebark pine site density per plot ranged from 0.0 to 0.067 sites/m^2, with a mean of 0.020. The ranking order of conifers from highest to lowest mean plot density on the road study area was fir, lodgepole pine, spruce, and whitebark pine. Although whitebark pine was the least common conifer, its densities were on average comparable to those on the ridge and south plot series. This suggests that nutcrackers are in fact transporting seeds a long distance from the seed source.

Scatterplots of plot densities for the ridge study area versus distance from the whitebark pine seed source reveal interesting differences in regeneration patterns (fig. 5). For lodgepole pine, densities increase with increasing distance from the whitebark pine seed source but with decreasing distance from regenerated stands of lodgepole pine in the lower subalpine forest zone. Regression analysis indicated a highly significant relationship ($r = 0.482$, df = 61, $P < 0.001$). Because much of the lower subalpine zone was dominated by lodgepole pine at the time of the fire, the restocking came from seeds in serotinous cones on site (Lotan 1976). Throughout the burn, young lodgepole pine trees are already producing cones and are a secondary seed source.

Although density increases slightly but nonsignificantly with distance on the spruce scatterplot (fig. 5), the curve is nearly flat with a dip at about 3,000 m. It is possible that seeds are blown into the ridge study area from both the higher and lower elevation seed sources. On the road transect there is, in fact, an increase in spruce density with distance from the whitebark pine seed source (Tomback and others 1989a).

The scatterplot for subalpine fir shows a negative relationship (fig. 5), suggesting that the primary fir seed source for the ridge is the high-elevation seed source. A regression analysis of density versus distance from the whitebark pine seed source is significant ($r = -0.355$, df = 61, $0.01 > P > 0.001$). Along the road transect, there is an increase in fir density with distance from the whitebark pine seed source, indicating that lower elevation forests are also contributing to fir regeneration (Tomback and others 1989a).

For whitebark pine, the scatterplot is a pronounced negative exponential curve, with a long tail of low densities beginning about 2 km. The regression analysis shows a highly significant relationship between density and distance ($r = -0.592$, df = 61, $P < 0.001$). Whitebark pine density also decreases with distance from the whitebark pine seed source along the road transect, as expected if the high-elevation source is the primary seed source ($r = -0.374$, df = 12, NS). The fact that whitebark pine

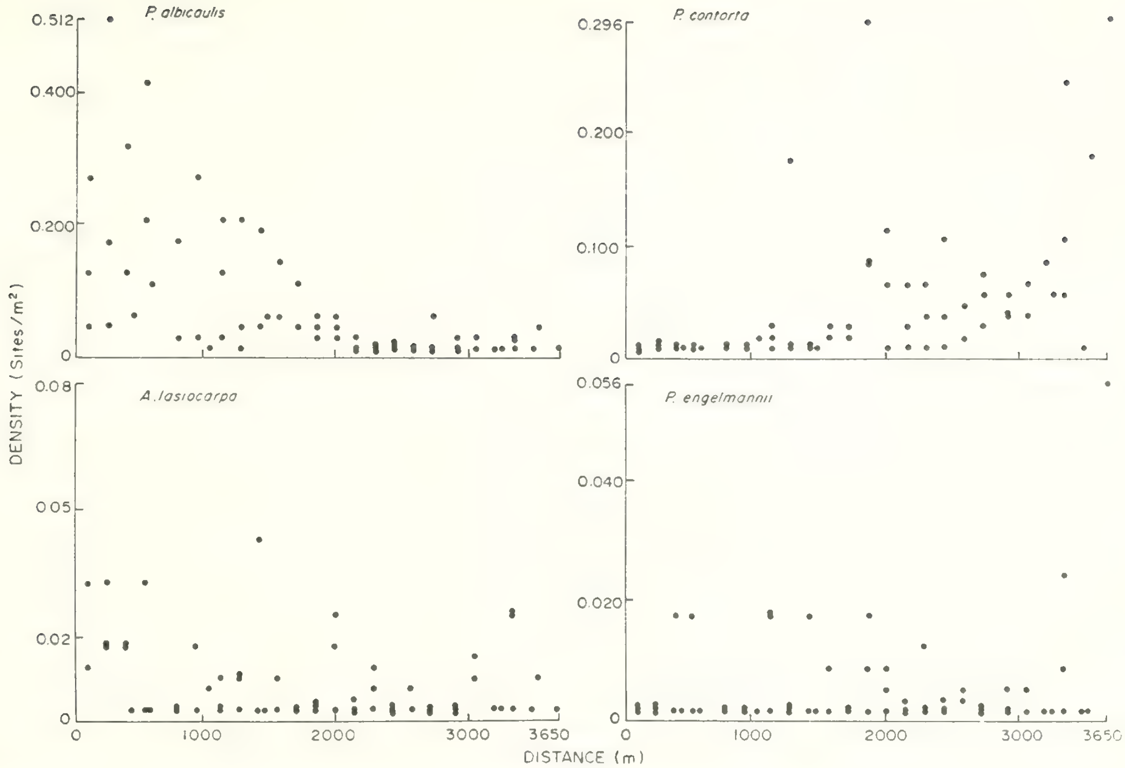

Figure 5—For the ridge study area of the Sleeping Child Burn, scatterplots of regeneration density versus distance from the whitebark pine seed source for four conifer species. Clockwise from left: whitebark pine, lodgepole pine, Engelmann spruce, and subalpine fir.

is regenerating up to 8 km from the single seed wall is an illustration of the seed dispersal effectiveness of Clark's nutcrackers.

A more meaningful regression analysis of the relationship between density (Y) and distance (X) for whitebark pine is based on a plot of $\log_{10}$ density versus distance. The result is a highly significant linear relationship ($r = -0.692$, df = 61, $P < 0.001$) described by the following regression model:

$$\log_{10}Y = -0.0005X - 0.806$$

This model may be used to formulate an equation to describe the negative exponential regeneration curve:

$$Y = (0.156)E^{-0.0005X}$$

where E is 10.

Regression analysis also indicates a significant relationship between whitebark pine plot density and elevation ($r = 0.608$, df = 61, $P < 0.001$). Unfortunately, the confounding effects of distance from the seed source and elevation cannot be separated statistically. Although some effects from elevation, perhaps in conjunction with site aspect, cannot be ruled out, whitebark pine grows well at elevations of 2,100 m and above in the Bitterroot National Forest (Arno 1988; Arno and Hoff 1989). Therefore, confounding elevation effects are unlikely on the ridge and road study areas.

In the Sleeping Child Burn, seed dispersal by nutcrackers has given whitebark pine a clear advantage over subalpine fir, the major climax species in seral communities in the upper subalpine. In particular, dispersal of whitebark pine seeds into the burn occurs even if wind patterns are unfavorable; dispersal of fir seeds from the same seed source can be impeded. The prevailing winds in the region during the time that conifers release seeds are from the west (Finklin 1983); the direction that subalpine fir seeds must travel from the seed source into the burn is toward the west. This may well account for the fact that the densities of whitebark pine are higher than those of fir on all aspects. Additional factors might include the greater tolerance of whitebark pine for open sites (Arno and Hoff 1989) and the occurrence of some whitebark pine regeneration in clusters; the loss of one seedling or tree at a site may still result in a mature tree. Of particular note, whitebark pine regeneration has extended 8 km or more into the burn from a single seed wall.

The advantage to whitebark pine in the Sleeping Child Burn may be explained by the size of the burn, wind patterns, and the difficulty of long-distance seed dispersal for the other conifers. The smaller Saddle Mountain Burn may provide some test of this hypothesis. There, we sampled 164 whitebark pine and 175 fir trees on 41 plots and 49 spruce, 286 lodgepole pine, and 29 Douglas-fir trees on

Table 3—Sample sizes and 1988 conifer regeneration densities for the Saddle Mountain Burn (Tomback and others 1989a)[1]

	Conifer species				
	WP	SF	ES	LP	DF
Number of sites	164	175	49	286	29
Area sampled (m^2)	10,410	5,980	1,580	1,170	1,580
Density per plot (sites/m^2)					
Range	0-0.160	0-0.280	0-0.200	0-1.24	0-0.160
Mean	0.042	0.046	0.030	0.323	0.019
SD	0.051	0.684	0.044	0.355	0.032

[1]WP = whitebark pine, SF = subalpine fir, ES = Engelmann spruce, LP = lodgepole pine, and DF = Douglas-fir, SD = standard deviation.

31 plots (table 3). At 43 percent of the whitebark pine sites, regeneration was in clusters of two to 10 seedlings or trees, with a mean of 1.98 per site. The oldest trees sampled were 21 years for whitebark pine, 16 years for fir, 22 years for spruce, and 17 years for lodgepole pine and Douglas-fir. Mean plot densities indicated the following ranking of conifers, from highest to lowest: lodgepole pine, whitebark pine and subalpine fir nearly equal, spruce, and Douglas-fir (table 3). A comparison of whitebark pine and fir densities for plots that were equal in sampling area (n = 27) indicated no difference (Mann-Whitney U test). As for the Sleeping Child Burn, the prevalence of lodgepole pine in the Saddle Mountain Burn may be the consequence of its prefire dominance in the area.

Relationships between density and distance from the whitebark pine seed source for all conifers resemble those for the Sleeping Child Burn. For lodgepole pine, the regression analysis of density versus distance indicates a trend toward increasing densities with distance (r = 0.320, df = 29, P = 0.079). This is consistent with primary seed sources and more favorable sites at lower elevations, as observed for the Sleeping Child Burn. In the case of Douglas-fir, density also increases with distance from the whitebark pine seed source, reaches the highest values between transect distances of 1,100 and 2,200 m, and then decreases. Douglas-fir is a lower subalpine and montane-elevation species (Pfister and others 1977); its distribution in the burn probably reflects the location of seed sources, wind patterns, and site suitability. The spruce scatterplot is nearly flat, with a sharp spike in density between transect distances of 1,700 m and 2,100 m. The explanation for Douglas-fir applies to spruce as well. Again, the scatterplot for subalpine fir indicates a strong inverse relationship between density and distance (fig. 6). This relationship is highly significant (r = –0.498, df = 39, P < 0.001), suggesting that the residual forest on the southwest edge of the burn is the principal seed source for this species.

For whitebark pine, the pattern of regeneration follows a negative exponential curve, as in the Sleeping Child Burn (fig. 6). The relationship between density and distance is highly significant (r = –0.822, df = 38, P < 0.001); however, the linear model based on $\log_{10}$ density is barely significant (r = –0.301, df = 38, P = 0.059):

$$\log_{10}Y = -0.0002X - 1.065.$$

The model for the negative exponential regeneration curve is

$$Y = (0.086)E^{-0.0002X}$$

where E is 10. Again, the effects of distance and elevation cannot be separated statistically (density versus elevation, r = 0.884, df = 38, P < 0.0001).

The slopes and intercepts of the linear models based on $\log_{10}$ whitebark pine density versus distance were compared for both burns (Greybill 1976). There were no significant differences between the models, suggesting that they may be used for management purposes or regeneration simulations in process models for comparable burns (Keane and others, in press; Keane and others, these proceedings).

In the smaller Saddle Mountain Burn, whitebark pine and subalpine fir have comparable regeneration densities. Because the mean plot density for subalpine fir is much higher in the Saddle Mountain Burn than in the Sleeping Child Burn, one or more factors must cause relatively higher numbers of subalpine fir seeds to land in the burn. In fact, the prevailing winds from the west in late summer (Finklin 1983) favor the dissemination of subalpine fir seeds into the burn from the seed source at the southwest edge. This and the smaller size of the burn probably

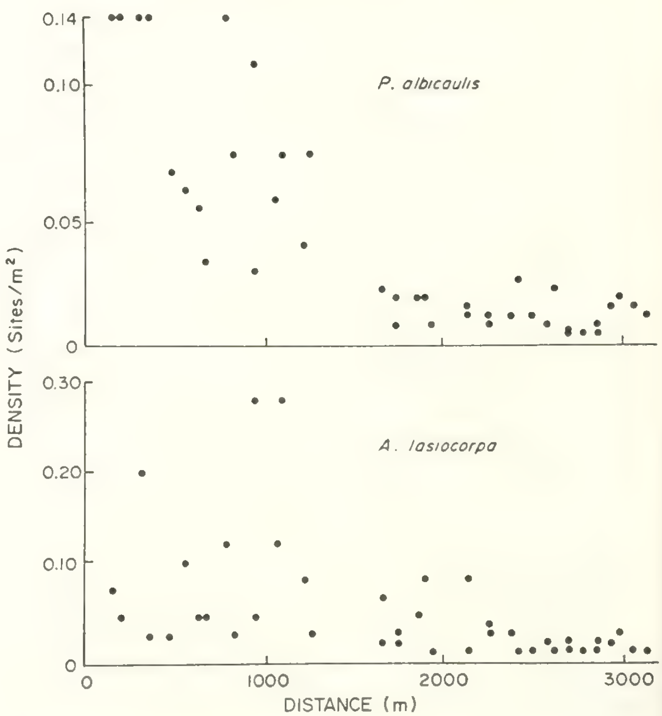

Figure 6—For the Saddle Mountain Burn, scatterplots of regeneration density versus distance from the whitebark pine seed source for whitebark pine (*P. albicaulis*) and subalpine fir (*Abies lasiocarpa*).

result in higher densities of subalpine fir seeds available for regeneration. The mean plot density for whitebark pine in the Saddle Mountain Burn is nearly identical to the mean plot density of the ridge plot series in the Sleeping Child Burn, suggesting that nutcracker seed dispersal activity may be the same. Comparison of regeneration patterns between the two burns indicates that whitebark pine may have an advantage over subalpine fir in situations where seed dispersal by nutcrackers is greatly superior to that of wind. Examples include (1) very large burns, where seed dispersal by nutcrackers extends greater distances than seed dispersal by wind, (2) areas where prevailing wind patterns are against the direction of the burn, and (3) burns where a seed source is more than 1 km from the perimeter of the burn.

ACKNOWLEDGMENTS

Discussions with Yan Linhart contributed greatly to the synthesis in the first part of the paper. We thank Steve Arno, Jim Brown, and Bob Keane for helpful discussions and advice concerning the whitebark pine regeneration studies. Steve Arno, Bob Keane, and Bill Schuster provided helpful comments on a draft manuscript. Mike Reuss contributed software expertise, Jan Driscoll advised us on statistics, and Ron Langley helped with statistical analysis. Funding (to DFT) and logistic support for the Sleeping Child and Saddle Mountain Burn fieldwork were provided by the Intermountain Research Station, Forest Service, U.S. Department of Agriculture.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from Wyman Schmidt)—If one wanted to attract nutcrackers to an area to have them do the seeding for you, what stand and site conditions would be most favorable?

A.—The sites used by Clark's nutcracker are extremely diverse. In fact, there seem to be few that they never use.

My impression, though, is that nutcrackers prefer more open situations with sparse ground cover.

Q. (from Richard Baker)—(1) Do Clark's nutcrackers migrate? (2) If so, would they ever carry whitebark pine seeds greater distances, such as, from one mountain range to another? (3) If so, why hasn't whitebark pine gotten to Colorado?

A.—(1) Nutcrackers remain at montane elevations all year, unlike those species that migrate south for the winter. However, nutcrackers periodically "irrupt" in great numbers from a montane region if there has been a widespread cone crop failure. Many search through the mountains for food, and flocks have been found hundreds of miles outside their range in some years, in such places as Carmel, CA. Annually, nutcrackers in some montane regions also undergo altitudinal migration, moving downslope in late fall and returning to the higher elevations in late spring.

(2) Nutcrackers are known to carry pine seeds 22 km or more, but it is unlikely that a bird would transport seeds hundreds of kilometers (an extreme case of "take-out food"?).

(3) We really don't know for a fact that whitebark pine has not been in the Colorado Rockies historically. Perhaps environmental conditions are now such that it cannot occur there; perhaps in the current conditions, limber pine is a serious competitor? Possibly, if conditions were to change, there would be a slow southward migration of whitebark pine. Alternatively, there may be a geographic barrier, such as distance, to continuous seed dispersal by nutcrackers. Some people have suggested that whitebark pine has a remnant distribution. If this is the case, range expansion to favorable, high-elevation locations may be impossible.

Q. (from Anonymous)—I missed the number of seeds stored per day.

A.—I estimated that each nutcracker in the Sierra Nevada stored around 850 seeds per day, for a total of about 35,000 whitebark pine seeds per season.

Q. (from Jack Losensky)—Have you found any indication of birds caching at the same site more than one time; are there sites with more than 30 seeds?

A.—I have never encountered a cache of more than 15 seeds or a germinated cache of seeds with more than 17 seedlings. It is unlikely that more than one bird would use the same site.

Q. (from Bill Shuster)—Have you identified any predation on nutcracker caches?

A.—In a series of experiments to determine the extent of cache predation, I buried caches of various sizes. Large and small caches were taken alike for a total of 85 percent loss. This is described in my 1980 paper in "The Condor." I believe *Peromyocus* was responsible.

PHYSICAL AND CHEMICAL TREATMENTS TO IMPROVE GERMINATION OF WHITEBARK PINE SEEDS

J. A. Pitel
B. S. P. Wang

ABSTRACT

Seeds of whitebark pine (Pinus albicaulis *Engelm.) were x-rayed, and those with full embryos were selected for the experiment. For intact seeds, no germination was observed for unstratified seeds; 23 percent germination was obtained for seeds stratified for 60 days. Treatment with GA_3 was not effective in improving germination of intact seeds. Following sulfuric acid scarification, unstratified seeds had 4.7 percent germination, while those stratified for 60 days had 41.3 percent germination. The best treatment to improve germination was clipping the seeds—excising a small piece of the seedcoat and gametophyte from the radicle end, exposing the root tip. With this treatment, germination rates of 61.3 percent and 90.7 percent were observed for unstratified and 60-day-stratified seeds, respectively. Some causes of dormancy of the seeds are discussed.*

INTRODUCTION

Whitebark pine (*Pinus albicaulis* Engelm.) occurs in subalpine areas in the northern Rocky Mountains and Coast Mountains of British Columbia through the Cascade Range to the southern Sierra Nevada. In Canada, the species has some importance in reclamation projects. The wood is also cut locally for lumber and mine timbers.

In a previous study with this species (Pitel and Wang 1980), results with three seedlots showed that embryo underdevelopment was the primary cause for poor germination. Only 19 to 30 percent of the seeds had embryos that were 75 to 100 percent full. Because of this, seed germination did not increase very much following cold or warm stratification or after various physical and hormone treatments. Another seedlot acquired recently (provided by Dr. Ray J. Hoff, Intermountain Research Station, Moscow, ID) was found to be very interesting as, unlike the previous three seedlots examined, more of the seeds contained fully developed embryos. The purpose of this study was to determine if this seedlot would respond more favorably to treatments with sulfuric acid, clipping, gibberellic acid, and cold stratification.

MATERIALS AND METHODS

Whitebark pine seeds of the 1974 crop, obtained from Gisborne Peak, near Priest River, ID, were classified according to the size and development of the embryos and endosperms (Simak 1980), and then surface-sterilized with calcium hypochlorite (4 percent available chlorine). For each experiment treatment, three replicates of 50 seeds (with mature embryos) were used. Physical treatments included soaking in concentrated (97 percent) sulfuric acid for 3.5 hours, followed by stratification for 30 and 60 days; and by clipping unstratified and 30- and 60-day-stratified seeds at the radicle end, removing a piece of the seedcoat and gametophyte tissue sufficient to allow exposure of the root tip.

Seeds were stratified at 4 °C in the dark under moist, aerated conditions. For hormone treatment, intact and sulfuric-acid-treated seeds were placed in a solution of gibberellic acid (GA_3 at 500 mg/L) for 24 hours. Germination was at 20 °C in continuous light for 30 days. Germination is based on seeds selected for fully developed embryos and gametophytes. Seeds were considered to have germinated if the radicles were at least 5 mm long, and showed geotropic curvature. Seeds were x-rayed with Kodak "M" films at 20 KV, 3 mA, 80 seconds, and 56 cm focus to film distance.

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Table 1—Percentage distribution of different embryo and female gametophyte types present in whitebark pine seeds from Idaho

Seed class	Female gametophyte type	Embryo type	Percentage
O	shrunken or full	absent	11.0
III A	full	50-75% full	37.5
IV A	full	75% to full	47.0
III B	shrunken	50-75% full	1.5
IV B	shrunken	75% to full	3.0

RESULTS AND DISCUSSION

Analysis by x-radiography showed that 84.5 percent of the seeds obtained from Idaho contained embryos that were larger than half of the embryo cavity. Most of these were seeds with full embryos. The percentage of seed included for each of the embryo and endosperm classes is described in table 1. The large proportion of seeds with full or almost full embryos indicated that embryo underdevelopment would not be a significant factor affecting the germination of this seedlot, as was the case in the previous study (Pitel and Wang 1980).

In contrast to the seeds from Idaho, seeds recently obtained (1986 crop) of whitebark pine from a high-elevation site (longitude 114 °37'; latitude 50 °06'; 2,164 m) in the Rocky Mountains Forest Reserve, AB, provided by the Alberta Forest Service, showed a very high percentage of empty and underdeveloped seeds. Following an attempt to upgrade the seed quality by flotation in cyclohexane (fig. 1) and x-radiography, only 10 percent of the seeds were found to have 50 to 100 percent fully developed embryos, according to the anatomical development classification of Simak (1980) (table 2). Figures 2 and 3 indicate that separation of many poor quality seeds can be achieved by use of cyclohexane. Pentane gave similar results. Because of the poor quality of the seeds from the Alberta source, we decided not to include this seedlot for physical and chemical treatments. Further studies of Canadian whitebark pine seeds with special reference to their anatomical development, upgrading of seed quality by pentane (Barnett 1971), and physical and physiological treatments for improving germination are planned.

Although the seeds from Idaho had a large percentage of mature embryos, none of the intact seeds germinated (table 3). Stratification for 60 days increased germination to 23.3 percent. The increased germination following cold stratification suggests the presence of physiological embryo dormancy. This is usually overcome after certain metabolic events that may result in decreased inhibitor and increased growth promoter content, increased energy charge, activation of the genome, and increased protein synthesis (for example, see Khan 1982). Gibberellic acid was not effective in improving the germination of intact whitebark pine seeds.

Figure 1—Separation of whitebark pine seeds into sinkers and floaters by use of cyclohexane.

Table 2—Percentage distribution of embryo size and female gametophyte development of Alberta whitebark pine seeds (based on 1,034 seeds x-rayed)

Seed class	Female gametophyte type	Embryo type	Percentage
O	shrunken or full	absent	27.9
II A	full	less than 50%	57.1
III A	full	50-75% full	7.3
IV A	full	75% to full	2.2
II B	shrunken	less than 50%	5.0
III B	shrunken	50-75% full	0.5
IV B	shrunken	75% to full	0.0

Table 3—Percentage germination using various cold stratification and physical and hormone treatments on whitebark pine seeds obtained from Idaho

Seed treatment	Days of stratification					
	Control^{0}	GA_3	Control^{30}	GA_3	Control^{60}	GA_3
Intact seeds	0	0	16.7	19.3	23.3	26.7
Sulfuric acid treated	4.7	14.7	20.7	18.0	41.3	32.7
Clipped	61.3	—	78.7	—	90.7	—

Figure 2—Analysis by x-radiography of seeds that floated following cyclohexane separation.

Treatment of seeds with sulfuric acid improved germination of both unstratified and stratified seeds. Germination of 41.3 percent was obtained after 60 days of stratification. These results suggest that the seedcoat is also a factor involved in the dormancy of whitebark pine seeds, either by restricting water and oxygen uptake, by mechanical restraint, or both. Treatment with sulfuric acid and gibberellic acid improved germination over that of the controls only for unstratified seeds.

Clipping resulted in the greatest improvement in germination. Unstratified seeds that were clipped had a germination rate of 61.3 percent. If the seeds were stratified for 30 and 60 days, germination increased to 78.7 percent and 90.7 percent, respectively. Sufficient seeds were not available for analysis by treatment with a combination of gibberellic acid and clipping. However, as shown in table 3, gibberellic acid had no effect on intact seeds, and even if most of the seedcoat was removed with sulfuric acid, germination only improved slightly.

Our results indicate that if the seeds have a high proportion of developed embryos, good germination can be obtained if treated as shown in table 3. Further studies are needed to clarify the exact cause of dormancy. It may be the result of a combination of physiological embryo dormancy and mechanical restraint, limited oxygen supply, and growth inhibitors imposed by the seed coat and female gametophyte tissue.

However, for whitebark pine seeds obtained from Canadian sources to date, the low percentage of seeds with fully developed embryos and gametophytes is the primary cause of poor germination. Studies are in progress to improve this situation by first identifying the best seed lots in British Columbia and Alberta and then upgrading the seed quality by flotation, such as with n-pentane. Treatment by warm stratification is being done to try to increase embryo size. Physical and chemical treatments (such as potassium nitrate and growth promoters) will be combined with methods to overcome possible physiological dormancy, such as cold stratification or alternating temperatures.

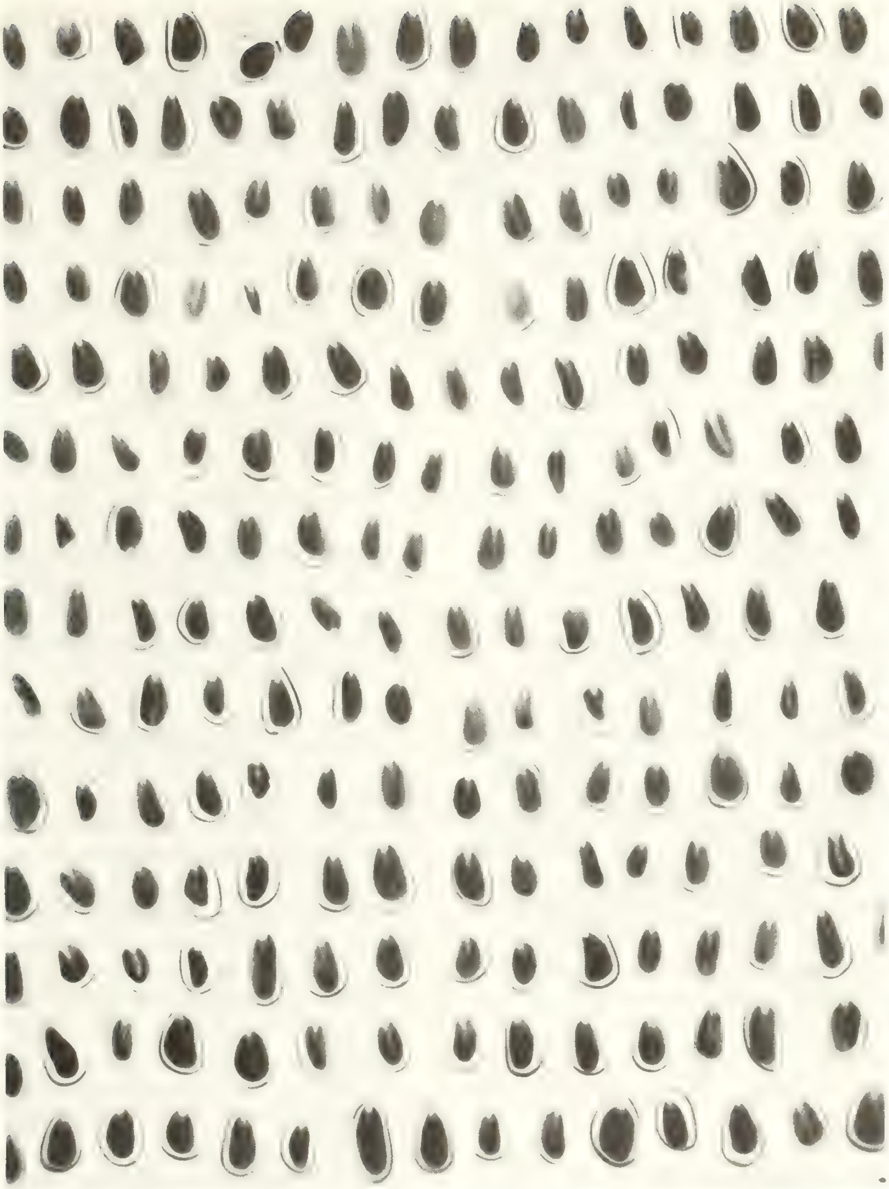

Figure 3—Analysis by x-radiography of seeds that sank following cyclohexane separation.

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EFFECTS OF TEMPERATURE AND TEMPERATURE PRECONDITIONING ON SEEDLING PERFORMANCE OF WHITEBARK PINE

J. Jacobs
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ABSTRACT

Four experiments explored the effects of temperature on the germination and seedling performance of whitebark pine (Pinus albicaulis). *While 1 month of stratification increased germination from 5 percent to about 40 percent, longer stratification periods (to 8 months) did not improve germination. Germination occurred throughout the 10 to 40 °C range with a broad optimum near 30 °C. Root growth occurred throughout the 10 to 45 °C range with an optimum near 30 °C. Long exposure (5 months) to low temperature (1.5 °C) lowered the temperature threshold for both germination and root growth. The apparent temperature range (perhaps 0 to 35 °C) and optimum (20 °C) for net photosynthesis at light saturation were lower than for germination and growth. While no preconditioning effect of light level (200 to 800 uE/M2*S) on the photosynthetic capacities of mature leaves was seen, photosynthesis increased progressively from needles preconditioned with winter, spring (5 °C day to 5 °C night), summer (15 °C day to 5 °C night), and abnormally warm (25 °C day to 15 °C night) temperatures.*

INTRODUCTION

The establishment of whitebark pine (*Pinus albicaulis* Engelm.) on a site must depend on its response to quantities of energy (light and heat), materials (water and nutrients), and destructive forces (fire, herbivory, and trampling) present at the site (Hutchinson 1957). The trees' response might depend, as well, on preconditioning with respect to water (May and others 1962), temperature (Tranquillini 1979), or even destructive forces (Ryan 1983).

The object of our research was to explore the effects of one environmental phenomenon, temperature, on whitebark pine's readiness to germinate, germination, root growth, and photosynthesis. The magnitude of temperature preconditioning effects was studied on one of these processes, net photosynthesis.

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METHODS

Seed Source

Seeds for studies of stratification, germination, root growth, and photosynthesis were collected from an *Abies lasiocarpa-Vaccinium scoparium* habitat type near Jardine, MT (Palmer Mountain, 2,652 m) in the autumn of 1987. They were stored under dry 20 °C conditions.

Stratification Time

To determine the effects of stratification time on germination rate, filled seeds were stratified for 0, 1, 2, 3, 5, or 8 months and germination rates were compared (Jacobs 1989). All seeds were x-rayed before stratification and empty seeds were discarded. To minimize the danger of fungal attack during stratification, the seeds were surface sterilized by soaking in 40-percent Clorox for 10 minutes and rinsing 10 times in distilled water to remove the Clorox (Wenny and Dumroese 1987). The seeds were then placed in nylon bags and soaked in clear running tap water for 48 hours. The imbibed seeds were surface dried, lightly dusted with Spurgon fungicide (Tetrachloro-para-benzoquinone 98 percent) and placed between two moistened blotter papers in plastic germination boxes (14 by 13 by 3.5 cm), 100 seeds per box. The seeds were stratified in a refrigerator (1.5 °C) for 0 to 8 months. When the stratification was complete, the stratification-germination boxes were transferred to a germination chamber (25 °C day, 15 °C night, and a 10-hour photoperiod). Germination occurred over a period of 1 to 3 months. After germination ceased, percent germination was calculated.

Germination Rates

To determine the effect of temperature on germination rate, the germination rates of seeds stratified at 1.5 °C for 2 to 3 months were compared at temperatures ranging from 5 to 50 °C (Jacobs 1989). Stratified seeds were placed on a temperature gradient bar with a temperature range of 5 to 50 °C and germinating seeds were counted over a period of 2 weeks. The temperature gradient bar was similar to that of Barbour and Racine (1967): three aluminum plates (one per species) 90 by 14.5 by 0.7 cm lay parallel and connected by tubes with 50 °C water

passed through at one end, and 4 °C isopropyl alcohol at the other. Each bar was coated with lacquer (to minimize Al^{+++} exposure) and a moist blotter. The blotter paper was kept moist by immersing its warm end in a tray of water, and by the condensation of water on its cold end. The bars were covered with plastic wrap and a plexiglass box top to minimize evaporation and temperature fluctuation. Stratified seeds were lined up across the bar in columns of 10, and with the columns 5 cm apart. Treatment temperatures were measured by placing the tip of a thermocouple on the blotter paper at each seed column. Seeds germinating in each temperature treatment were counted every 48 hours for 2 weeks. The experiment was replicated on three dates (July 15, 1988; December 2, 1988; and February 27, 1989).

Root Growth Rates

To determine the effects of temperature on root growth rates, the root growth rates of plants growing under cool temperatures were compared with those of plants growing under warmer conditions (Jacobs 1989). The seeds were stratified in a refrigerator (1.5 °C) for 1 to 3 months. When the stratification was complete, the stratification-germination boxes were transferred to a germination chamber (25 °C day, 15 °C night, and a 10-hour photoperiod). Freshly germinated seeds were transferred to the temperature gradient bar to measure root growth rates at temperatures ranging from 4 to 48 °C. The bar was coated with lacquer (to minimize Al^{+++} exposure), a moist blotter, and, 1 mm above the blotter, a glass plate. Each bar was tilted at a 45° angle so the roots would grow geotropically straight down between the blotter and the glass and in a region of constant temperature. The blotter paper was kept continuously moist by immersing its warm end in a tray of water, and by the condensation of water on its cold end. The bars were covered with a plexiglass box top to minimize evaporation and temperature fluctuation. Root lengths were measured when seeds were placed on the bar and every 48 hours thereafter for 8 days. Bar temperatures at sites where the roots grew were measured by inserting a thermocouple between the glass plate and the blotter paper. The experiment was replicated on four dates (April 26, May 6, June 1, and June 22, 1988).

Photosynthetic Rates

Seeds collected in 1984 were stored, stratified, planted, and started in the Coeur d'Alene nursery. We obtained 2-year-old *Pinus albicaulis* seedlings as bare root stock in October of 1987. The seedlings were transferred to 3.8- by 20.3-cm "conetainer" tubes in a soil composed of equal volumes of Fort Ellis loam, sand, and peat; steam pasteurized at 180 °F; and maintained in a greenhouse at 15 °C and natural photoperiod over winter. In March 1988, seedlings were transferred to a vernalization room (5 °C night/9 °C day) to prevent breaking dormancy.

Seedlings were preconditioned for 35 days (April 19 to May 24, 1988) at three day-night temperature combinations and two light levels. Temperatures in the three growth chambers were 25 °C day/15 °C night (hotter than field conditions), 15 °C day/5 °C night (similar to July-August), and 5 °C day/5 °C night (similar to April-May) (Weaver 1980, this proceedings). In each temperature regime six seedlings received light levels equal to 33 percent of full sun (800 uE/M2*S = micro-Einsteins PAR (= micro moles of photosynthetically active radiation) per meter squared per second and simulating light levels in an open stand) and six seedlings received 10 percent of full sun (200 uE/M2*S and simulating understory conditions in a fully shaded spot, Wellner 1948). Light was provided with fluorescent and incandescent light (twelve 60-watt incandescent, and sixteen 6-ft cool white fluorescent tubes) shaded, in the low-light case, with steel screen. Light levels measured in a mature whitebark pine stand (52 percent cover, Weaver and others, this proceedings) were 250-1,619 uE/M2*S in sun spots and 140-230 uE/M2*S in full shade. The photoperiod was 14 hours, equivalent to the photoperiod 1 month before bud break (lat. 45° N., May, Long 1969; Schmidt and Lotan 1980). In spite of the short days, seedlings in the 25 °C day-15 °C night and 15 °C day-5 °C night chambers broke bud dormancy during preconditioning; the resultant growth was clipped off so only year-old needle photosynthesis and respiration were measured. The base of each conetainer tube was submerged in 2 cm of water to prevent water stress.

Photosynthetic rates of seedlings given the six preconditioning treatments were measured, via CO_2 exchange, at four temperatures (0, 15, 25, and 35 °C) and five light levels (dark, 210, 420, 1,050, and 1,580 uE/M2*S) between May 24 and June 14. Six 5-cm-diameter by 15-cm-long plexiglass chambers, one for a seedling from each preconditioning treatment, were cemented side-by-side in a rectangular water jacket. The air was mixed by turbulence as it flowed from top to bottom of the tubular chamber. Chamber air temperatures were maintained by pumping water from a water bath through the water jacket surrounding the chambers. The roots were outside the chambers and therefore near room temperature (21 °C). A thin copper-constantan thermocouple was inserted into a *Pinus albicaulis* needle and placed in the chamber as an index of leaf temperature. The chambers were lighted with a xenon lamp and light levels were regulated using wire screens. Plumbers' "bolwax" was used to seal the conetainers into the chambers and to seal the soil-root systems out of the chambers.

CO_2 flux density was measured with an Analytical Development Company open system IR gas analyzer. Air from the ceiling of a hallway was pumped through copper tubing in the water bath to adjust its temperature, through a silica gel to dry it, and split for reference and analysis air. Both reference and analysis air were, thus, very dry. The reference air was passed through a flow regulator and to the reference port of the gas analyzer. The analysis air went to a manifold that directed it to the six chambers with the seedlings. The analysis air was directed through one of the six chambers at a time, to a flow regulator, and then to the analysis port of the gas analyzer. Flow rate for reference and analysis air was maintained at 150 mL/minute. The difference between reference and analysis air was checked with an

empty chamber at the beginning and end of each day to verify that the CO_2 concentrations were equal.

The experiment was replicated six times. Each run began at 0 °C and progressed through four temperature steps to 35 °C; the plants were allowed 1 hour to equilibrate after each adjustment. Within each temperature level net photosynthesis was measured at irradiation levels including dark (for respiration), four light levels up to 1,580 uE/M2*S, and a second end-of-run measurement of dark respiration; the plants were allowed to equilibrate 20 minutes between changes in light levels. Since it took 2 days to complete one replication (run through the four temperatures and five light levels), the seedlings were returned to their preconditioning chambers for the night.

Whole-seedling photosynthetic rates were converted to leaf area rates by dividing whole seedling photosynthesis by the total leaf area of the seedling. All the needles were plucked from the seedling and run through a Licor optical planimeter to measure the projected area (Kvet and Marshall 1971). In contrast to a platelike leaf—whose total area is calculated by doubling projection areas—a needle is a three-sided triangular prism formed by division of a cylindrical needle bundle into five needles. Since the cylinder splits from the tip down, each needle is curved outward from the axis so that the projectable area is roughly equivalent to a radial section (0.5 diameter by ht) through the needle bundle cylinder. Assuming this, one sees that total needle area is proportional to projectable area as needle radius is to needle circumference [that is, r (for one radial side) + r (for the second radial side) + $2*pi*r/5 = 1.256r$ (for the circumferential side)] so total needle area can be calculated by multiplying projected area by 3.256. We recognize that total leaf area overestimates functioning leaf area and therefore underestimated absolute photosynthetic rates (Carter and Smith 1985), but believe the units are adequate for comparisons designed to determine the effects of light and temperature levels.

Statistical analysis of the data was by analysis of variance across the six replications with a Newman-Kuels comparison of means (Snedecor and Cochran 1980).

RESULTS AND DISCUSSION

Stratification

Exposure to moist cold is a dormancy-breaking requirement for many species including almost half of the pines (Schopmeyer 1974). Since whitebark pine usually exhibits low germination rates in standard tests, we tested the hypothesis that the 1-month stratification time usually applied is less effective than a stratification time approximating the 5 to 8 months received naturally (Weaver 1980). Germination rates were 4 percent, 68 percent, 38 percent, 41 percent, 52 percent, and 38 percent for seeds stratified for 0, 1, 2, 3, 5, and 8 months, respectively. We conclude that stratification beyond 1 month does little to increase germination and speculate that a short stratification time has been naturally selected, because it prevents fall germination without any chance of delaying spring germination. This conclusion is bolstered by parallel tests (Jacobs 1989) that show 1-month stratification times were required for species from high (long-winter) altitudes (whitebark pine), middle altitudes (lodgepole pine), and low (short-winter) altitudes (limber pine). We speculate that the low germination rates observed are due in part to seed defect and in part to other dormancy mechanisms that reserve live seed for succeeding years (McCaughey 1989 [whitebark pine]; Perry 1989 [lodgepole pine]).

Temperature and Germination

Our tests show that, newly stratified whitebark pine seeds, germinate at temperatures ranging from 10 to 40 °C and that, while germination rates of specific lots of 10 seeds vary from 0 to 50 percent at most temperatures in this range, germination rates tend to be slightly higher in the 25 to 35 °C range than at cooler or warmer temperatures (fig. 1A). Germination of middle-altitude lodgepole pine and low-altitude limber pine occurred in the same 10 to 40 °C range as the high-altitude whitebark pine. During our stratification studies we saw that, if seeds are kept under cold conditions (1.5 °C) for longer periods of time (over 5 months), most dormancy-broken seeds will germinate. Since stratification is probably completed in the early winter, germination in moist forest soils is likely under temperature and/or endogenous control for most of the winter. If so, germination is expected in the spring near the time of snow melt.

Temperature optima may drop slightly with decreases in altitude from 25 to 35 °C for whitebark, 15 to 35 °C for lodgepole, and 15 to 25 °C for limber pine (Jacobs 1989). We speculate that, because lower temperatures precede the warmer temperatures of late spring, seeds with a lower optimum probably germinate first and are deeper rooted at the onset of any summer drought. If so, natural selection at lower, drier altitudes, where limber pine was collected, probably favors a lower temperature optimum than that favored at higher moister altitudes where whitebark pine predominates.

Temperature and Root Growth

Our tests show that, in newly stratified whitebark pine seeds, root growth can occur at temperatures between 10 and 45 °C and that, at the temperature optimum (25 to 35 °C), root extension of new germinants is 5 to 15 mm per day (fig. 1B). Root growth of high-altitude whitebark pine, middle-altitude lodgepole pine, and low-altitude limber pine has similar ranges (10 to 45 °C) and optima (30 °C) (Jacobs 1989). During our stratification experiments we also saw that, if seeds germinate after long (5 months) cold (1.5 °C) storage, root growth will occur at temperatures below the range reported. We conclude that in nature, germination must produce roots near snow melt, most growth occurs at suboptimal temperatures, and high-temperature stress is rare or nonexistent for most roots. This assertion is supported by soil temperature data at 5 cm depth from level grasslands just below the conifer zone at Bozeman, MT, and Casper, WY (NOAA 1985). Of the 6 months with average maximum

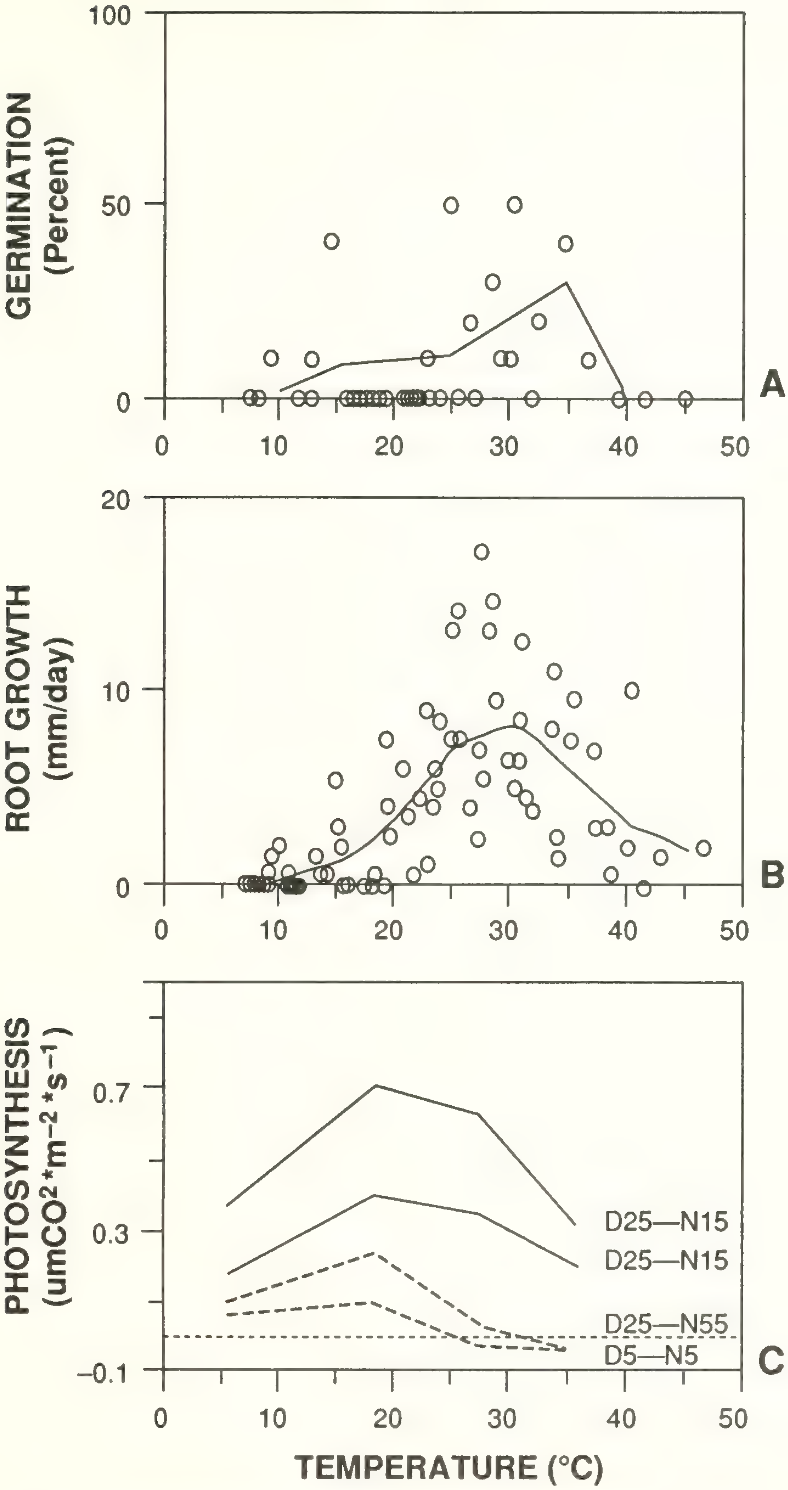

Figure 1—Effect of temperature on seed germination, root growth, and net photosynthesis: (A) Percent germination in 33 lots of 10 seeds tested at temperatures between 5 and 45 °C. The line passes through the median of non-zero values. (B) Initial growth rates (mm/day) of 71 roots grown at temperatures between 5 and 50 °C; the line passes through the median of non-zero values. (C) Photosynthetic rates at saturation for plants preconditioned at spring (5 °C day to 5 °C night), summer (15 °C day to 5 °C night), and warmer than natural (25 °C day to 5 °C night) conditions. Plants preconditioned under the hot conditions (solid lines) and low light (200 uE/M2*S) had higher photosynthetic rates (upper solid line) than the chlorotic plants preconditioned under high light (800 uE/M2*S).

temperature above 10 °C, only 3 have average maximum temperatures above 20 °C and maximum temperatures of 30 °C are reached rarely, if at all. If maximum temperatures almost never exceed 30 °C at 5 cm, the inhibition of root growth observed there (Weaver 1981) is more likely due to drought than high temperature; both factors may be important in more superficial layers.

Photosynthetic rates for ecologically and genetically related *Pinus cembra* increase fourfold as average soil temperatures rise from 0 to 8 °C (Tranquillini 1979); the increase in photosynthesis with increases in average soil temperature may indicate the daily duration of root activity; that is, hours above a root growth minimum of 10 °C.

Temperature and Photosynthesis

Net photosynthesis rises with increasing light from 0 to a maximum near 1,050 uE/M2*S for seedlings preconditioned under naturally occurring conditions. *Pinus contorta* (Dykstra 1974) and *Picea engelmannii* (Hadley and Smith 1987) were also light saturated at about 50 percent of full sun. While we saw no consistent difference in photosynthetic rates of mature leaves preconditioned for 1 month at 200 or 800 uE/M2*S, shade leaves might have been formed if branches had been shaded during needle initiation (Jacobs 1989).

Net photosynthesis at light saturation probably occurs at all above-freezing temperatures. It occurs at –4 °C in *Pinus cembra*, a close ecologic, taxonomic, and genetic relative (Tranquillini 1979), and in whitebark pine was shown to occur at 5 °C, was maximum near 20 °C, and declined significantly above 20 °C (fig. 1C). The temperature optimum for photosynthesis of *Pinus contorta* is also near 20 °C (Dykstra 1974). Dark respiration increased slightly from 5 °C (0.13 μmole $m^{-2}sec^{-1}$) to 30 °C (0.19 μmole $m^{-2}sec^{-1}$) and rose significantly as 35 °C (0.32 μmole $m^{-2}sec^{-1}$) was approached (Jacobs 1989). Despite the fact that both germination and root growth occur in the soil at temperatures lower than air temperature, both apparently have higher temperature cardinal points (minimum 10-optimum 30-maximum 40 °C) than does photosynthesis (0 min, 25 opt, and 35-40 °C, fig. 1)— a process proceeding at air temperature.

Net photosynthetic rates of whitebark pine are affected by temperature preconditioning (reviewed for other timberline species by Tranquillini 1979). Studies of photosynthesis of *Pinus cembra* (Tranquillini 1979) showed no photosynthesis during the winter months and *Pinus albicaulis* probably behaves similarly. Warming from winter to simulated spring (day 5 °C-night 5 °C) and summer (day 15 °C-night 5 °C) temperatures increased photosynthetic rates from 0.00 to 0.06 and 0.19 μmole $m^{-2}sec^{-1}$, respectively (fig. 1C). Further warming, to temperatures of 25 °C day-5 °C night, not even experienced in dry grasslands below, increased photosynthetic rates to 0.38-0.69 μmole $m^{-2}sec^{-1}$ (fig. 1C). The increase in net photosynthetic rates with higher temperature preconditioning must be primarily due to increases in gross photosynthesis or decreases in photorespiration—because differences in preconditioning temperature caused no difference in dark respiration rates. Light preconditioning had no effect on photosynthetic rate under spring or summer conditions; under warmer than natural preconditions, however, net photosynthesis of plants preconditioned with low light (200 uE/M2*S) was significantly higher than that of plants preconditioned with higher light levels (800 uE/M2*S).

Acclimatization (preconditioning) results suggest that—with adequate water and with competitor reduction, perhaps by fire or management—whitebark pine might survive under the warmest temperature conditions in our region. The trees may have used this capability in surviving the hypsithermal, a warm dry postglacial period, that deforested some of the highest sites in our region (for example, the Bighorn and Beartooth Mountains). This possibility is supported by the vigorous growth of trees transplanted from high forests to lawns in the valley below where their success surely depends on both heavy watering and the elimination of less cold-tolerant competitors such as *Pinus ponderosa*, *Psuedotsuga menziesii*, and *Abies lasiocarpa* (Arno and Weaver, this proceedings).

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from P. Kolb)—Do shaded seedlings have lower compensation points than sun-grown seedlings?

A.—Our growth chamber lights were not as bright as sunlight (1,600 uE/M2*S) so different light levels really refer to a light shade (800 uE/M2*S)—rare in the field—and a deep shade (200 uE/M2*S). Plants preconditioned in deeper shade usually had slightly lower compensation points (Jacobs 1989), but I doubt that the differences were statistically significant. It would be interesting to compare compensation points of sun and shade needles in the field.

Q. (from P. Kolb)—Why are photosynthetic rates of your shade-conditioned seedlings higher than those of your sun-conditioned seedlings?

A.—Light preconditioning had no differential effect on plants grown under normal spring (5 °C day-5 °C night) or summer (15 °C day-5 °C night) conditions. Plants grown at high temperature (25 °C day-15 °C night) with relatively high light levels (800 uE/M2*S) were chlorotic and therefore demonstrated lower photosynthetic rates than plants preconditioned at lower light levels (200 uE/M2*S).

Q. (from D. Mattson)—How does photosynthetic performance of whitebark pine under different light and temperature conditions compare with that of associated conifers (*Abies lasiocarpa*, *Picea engelmannii*, or *Pinus contorta*)?

A.—Lodgepole (Dykstra 1974) and Engelmann spruce (Hadley and Smith 1987) are similar to whitebark in light saturation levels (50 percent of full sun) and temperature optima (20 °C). Your question would be answered best with one experiment comparing all four species with uniform methods. Even these data would provide only a partial explanation of shade and temperature tolerance, as information on photosynthesis should be integrated with information on other processes (such as, respiration rates) to understand the carbon balance (growth) of the tree. Models integrating a variety of environmental factors will be required to predict the distribution and growth of whitebark pine; the models of Tranquillini (1979) and Keene (this proceedings) are relevant.

BIOTIC AND MICROSITE FACTORS AFFECTING WHITEBARK PINE ESTABLISHMENT

Ward W. McCaughey
T. Weaver

ABSTRACT

To enhance establishment of future whitebark pine (Pinus albicaulis) *forests, information is needed on the physical and biological factors affecting whitebark seed germination and seedling establishment. This paper summarizes the first-year results of field examinations designed to evaluate predator and seedbed factors affecting whitebark pine establishment. Predator effects were estimated by recording seedling emergence under four levels of predator exclusion (free predator access, rodents excluded, birds excluded, and both rodents and birds excluded). Rodents ate or removed 100 percent of available surface-sown seeds. Emergence was higher on plots excluding rodents only and significantly higher on plots excluding rodents and birds. Seedling emergence did not differ significantly between mineral (although numerically higher) and litter seedbeds.*

The effects of three seedbed factors were also examined by comparing seedling emergence under three light levels (open, 25, and 50 percent shade cover), two seedbed conditions (mineral and litter), and two sowing depths (on surface and 0.8 to 1.6 inches beneath surface). Buried seeds had significantly higher emergence rates than did surface-sown seeds. Even though the first season was hot and dry, 78 percent of seedlings survived.

INTRODUCTION

In the Northern Rocky Mountains, whitebark pine (*Pinus albicaulis* Engelm.) is important for watershed protection, esthetics, ornamental planting, and wildlife food and cover. Relatively pure whitebark pine stands provide cover in timberline and subtimberline zones little occupied by other tree species (Arno and Hoff 1989). Whitebark seeds are an important food source for grizzly (*Ursus arctos horribilis*) and black bear (*Ursus americanus*) (Craighead and others 1982; Kendall 1983; Knight and others 1987) and a supplemental food source for birds (Tomback 1982; Vander Wall and Hutchins 1983) and other small animals (Hutchins and Lanner 1982). Despite these merits, it forms only a minor component of forest communities that are commercially harvested. It has minimal significance for timber production because of its slow growth and generally poor form characteristics (Arno and Hoff 1989). Information on regeneration of whitebark is sparse because of its low commercial value and previously unrecognized alternative uses.

Current environmental conditions apparently favor whitebark pine mortality over establishment. Fire suppression practices over the past few decades have allowed successional replacement of whitebark by shade-tolerant fir and spruce (Arno 1986). Whitebark pine is highly susceptible to the introduced European disease white pine blister rust (*Cronartium ribicola*) even on trees with disease-resistant parents (Hoff 1980). Extensive mortality occurs in areas where the alternate host *Ribes* is abundant. The native mountain pine beetle (*Dendroctonus ponderosae* Hopkins) devastates stands of mature whitebark pine during years when climatic factors are favorable for beetle survival (Amman 1982). Mortality from the mountain pine beetle releases late-successional species such as subalpine fir (*Abies lasiocarpa*) and Engelmann spruce (*Picea engelmannii*).

The probability of natural regeneration of whitebark pine in wildlife-sensitive areas likely is decreasing and there is a need to reverse that trend. However, little is known about germination success rates of whitebark pine under natural conditions (Eggers 1986). Weaver and Dale (1974) examined established regeneration of whitebark pine in undisturbed climax communities of whitebark pine. Whitebark pine reproduction was apparently most successful in openings created by fallen trees or incomplete initial seeding of whitebark. Seedling survival within nutcracker caches was as high as 56 percent the first year and 25 percent by the fourth year, but the actual germination percent of all seeds "sown" by the nutcracker is unknown (Tomback 1982).

Management of whitebark pine forests will require management of competitors, disease, and the tree itself. Wildfires or prescribed burns may be needed to maintain whitebark in areas where it is seral. Exotic diseases must be managed, and where fire or disease mortality cannot be reduced, regeneration must be increased to compensate. Studies of the regeneration process will contribute to this establishment.

This paper reports first-year results of a study designed to determine the effects of biotic and microsite factors on seed survival, seedling emergence, and seedling survival,

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and on subsequent seedling survival for the first 3 years after germination. Five objectives of this study are to:

1. Determine differences in seed loss due to bird and small mammal predators when seed is surface sown (simulating tree dispersal) rather than buried 0.8 to 1.6 inches in soil (simulating burial by Clark's nutcracker [*Nucifraga columbiana]*).
2. Compare seed emergence and seedling establishment between surface-sown seeds and seeds buried 0.8 to 1.6 inches in soil.
3. Compare seed emergence and seedling establishment on mineral, litter, and burned seedbeds.
4. Compare emergence and seedling establishment under 100, 50, and 25 percent of full sunlight.
5. Record survival rates and factors limiting survival of natural seedlings for the 3-year period following germination.

STUDY AREA AND METHODS

The experimental site is classified as an *Abies lasiocarpa-Pinus albicaulis/Vaccinium scoparium* habitat type (Pfister and others 1977) recently occupied by a lodgepole pine forest. Its soils are classified as Typic Cryorthent, sandy skeletal and well drained. Soil pH values range from 4.7 to 5.5. The elevation is 8,700 ft MSL with 0 to 25 percent slopes and a northeast aspect.

The study area is located within section 14, township 9 south, range 9 east on the Gardiner Ranger District of the Gallatin National Forest just north of Yellowstone National Park (fig. 1), and near the southwestern corner of the Absaroka Beartooth Wilderness approximately 5.5 air miles east of Gardiner, MT.

Study plots were established on a 15-acre clearcut that is connected on one side to a large clearcut (50 acres) called the Palmer Coop timber sale. The Palmer Coop sale was harvested during the winter of 1985-86. Approximately 17,000 to 20,000 board feet per acre of timber were harvested from the sale area and 10 to 15 tons per acre of slash were left on the site. The species and percents of volume harvested were: live lodgepole pine (*Pinus contorta*)-75 percent, dead lodgepole-13 percent, Engelmann spruce-4 percent, subalpine fir-4 percent, and whitebark pine-4 percent. The study area is bordered by mature timber of similar composition on the south, west, and north sides.

Study Design

A factorial design (table 1) was used to evaluate the effects of seed predators, light levels, seedbed conditions, and seed sowing depths on the germination and survival of whitebark pine. Three subsites (replicates) were subjectively chosen within the clearcut as representative, similar, and suitable for plot establishment. The subsites had minimal amounts of logging slash, large areas of undisturbed litter, and represented the total stand conditions. Figure 2 is a schematic plot representation of one replication of each predator exclusion (EA = exclude all predators, ER = exclude rodents only, EB = exclude birds only, EN = exclude none)-shade level-seedbed condition-sowing depth combination. Plots were randomly located in each replicate.

The burned seedbed level for the seedbed condition factor was not used for the 1988 analysis because wet weather conditions in 1987 delayed burning and we could not establish plots. Mineral seedbed plots were located on scarified skid trails or hand-scalped when scarified areas could not be found.

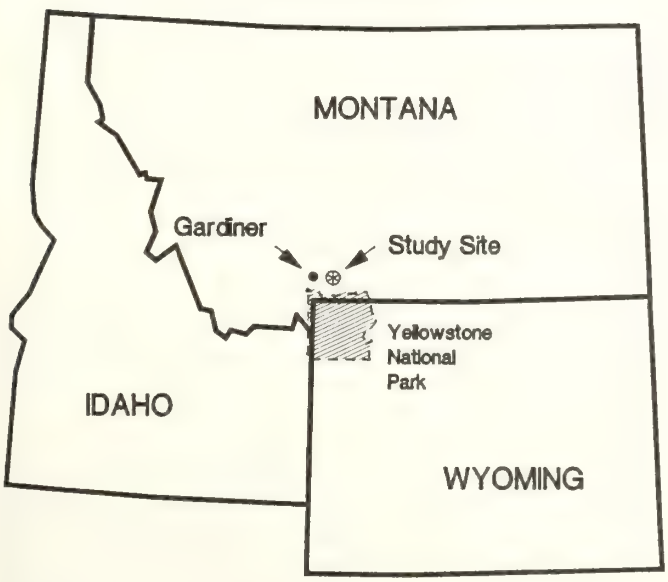

Figure 1—Study site location. Gallatin National Forest, Section 14, Township 9 south, Range 9 east, Montana Principal Meridian.

Table 1—Factors and factor levels

Factor	Levels
1. Predator exclusion	4
a. Exclude birds and rodents (EA)	
b. Exclude rodents only (ER)	
c. Exclude birds only (EB)	
d. Exclude none (EN)	
2. Shade level	3
a. No shade	
b. 25 percent shade	
c. 50 percent shade	
3. Seedbed condition	3
a. Mineral (1988 analysis)	
b. Litter (1988 analysis)	
c. Burned (1989 analysis)[1]	
4. Sowing depth	2
a. Surface sown	
b. Seed buried (0.8-1.6 inches)	
5. Replication	3

[1]First-year results did not include a burned seedbed treatment.

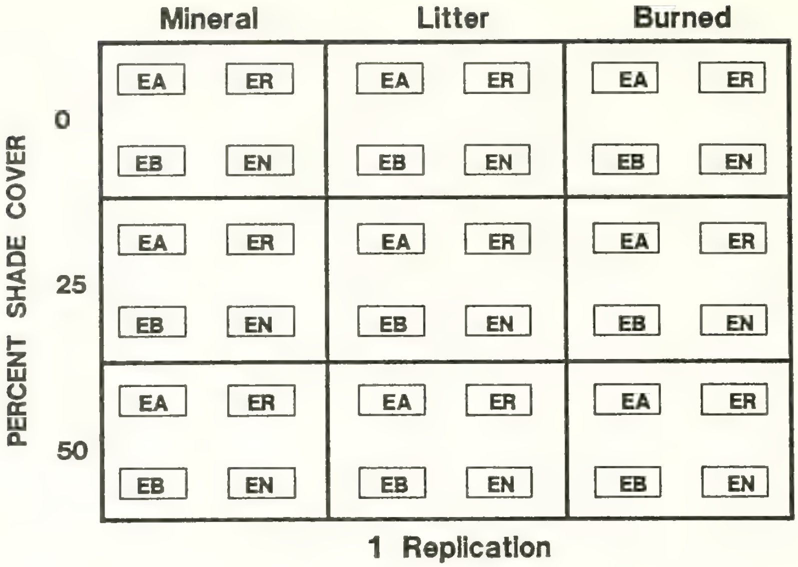

Figure 2—Schematic layout of study design showing all the treatment combinations in one of three replications. In the field, treatment combinations were located randomly.

Plot Layout

Within each subsite, 24 plots were established to represent all combinations of four predator exclusion levels, three shade levels, two seedbed conditions, and two sowing depths (fig. 2). Plots were rectangular (1.6 by 6.5 ft) oriented north-south. The south half (1.6 by 3.25 ft) of each plot was seeded in the fall of 1987 and the north half was seeded in the fall of 1988.

Each plot was subdivided into 40 subplots measuring 3.9 by 4.29 inches. Within each subplot two seeds were planted, one surface sown and one buried. The surface-sown seed was placed on the ground surface in the north half of each subplot. The buried seed was placed 0.8 to 1.6 inches below the surface level in the south half of each subplot. The buried seed was covered by the appropriate seedbed material (mineral soil or forest litter).

A total of 5,760 whitebark pine seeds were planted in 1987. The seed was collected in 1985 from trees at the same elevation as the study area and only 0.25-mile distant. All seeds were x-rayed and only filled seeds were planted.

Shade levels were imposed with slatted roofs. Four 6-ft-tall steel posts were installed at the corners of an imaginary 4- by 8-ft rectangle overtopping but slightly to the south of each plot to be shaded. A 4- by 8-ft-long wood frame was constructed with 2- by 4-inch lumber and attached to the steel posts 40 inches above the ground. A 4- by 8-ft section of wood snow fence was suspended on the wood frame. The 50 and 25 percent shade levels were simulated by either leaving all the wood slats in the snow fence or by eliminating every other slat, respectively.

Screen wire was used to exclude seed predators from the plots. Plots exposed to all predators were unscreened. Plots protecting seeds from all predators were completely covered using hardware cloth with 0.25-inch square holes (fig. 3a). Plots for protecting seed from birds only were covered by screen with 2- by 3-inch wide holes (fig. 3b). Plots excluding small mammals only were completely enclosed by a 30-inch high fence of 0.25-inch hardware cloth. The rodent fence was designed to exclude rodents but allow avian predators to fly into the plots. The top of the fence therefore had an 8-inch lip, bent outward from the plot. A 6-inch piece of tin flashing had to be attached to the underside of the lip to effectively exclude rodents (fig. 3c). The bottoms of screens were buried 4 to 6 inches deep on plots excluding birds and rodents and plots excluding rodents only. The bottom edge of the buried screen had a 2-inch lip bent outward from the plot to minimize the chance of rodents tunneling under the screen. Screening techniques for the control of seed predation were suggested by Curt Halverson, Fish and Wildlife Service, U.S. Department of the Interior, Fort Collins, CO.

Measurements

Counts of whitebark pine emergence were made periodically on all plots. Counts started on June 16, 1988, just 3 weeks after snowmelt. Seedling counts were measured and recorded weekly until the first of August and bimonthly from August to the first of October. Emergents were marked with colored plastic toothpicks; different colors indicated the week they emerged. A hypothetical cause and week of mortality were assigned to all seedlings that died.

Gravimetric soil moisture was measured on 6 of the 24 germination plots at each of the three replicates. These six plots comprised one plot from each combination of mineral and litter seedbed and 0, 25, and 50 percent shade cover. Soil from the upper 2 inches of the A horizon was collected in gravimetric soil cans and sealed for transport from the field to the laboratory. Percent soil moisture was determined with gravimetric methods (Soil Survey Staff 1975).

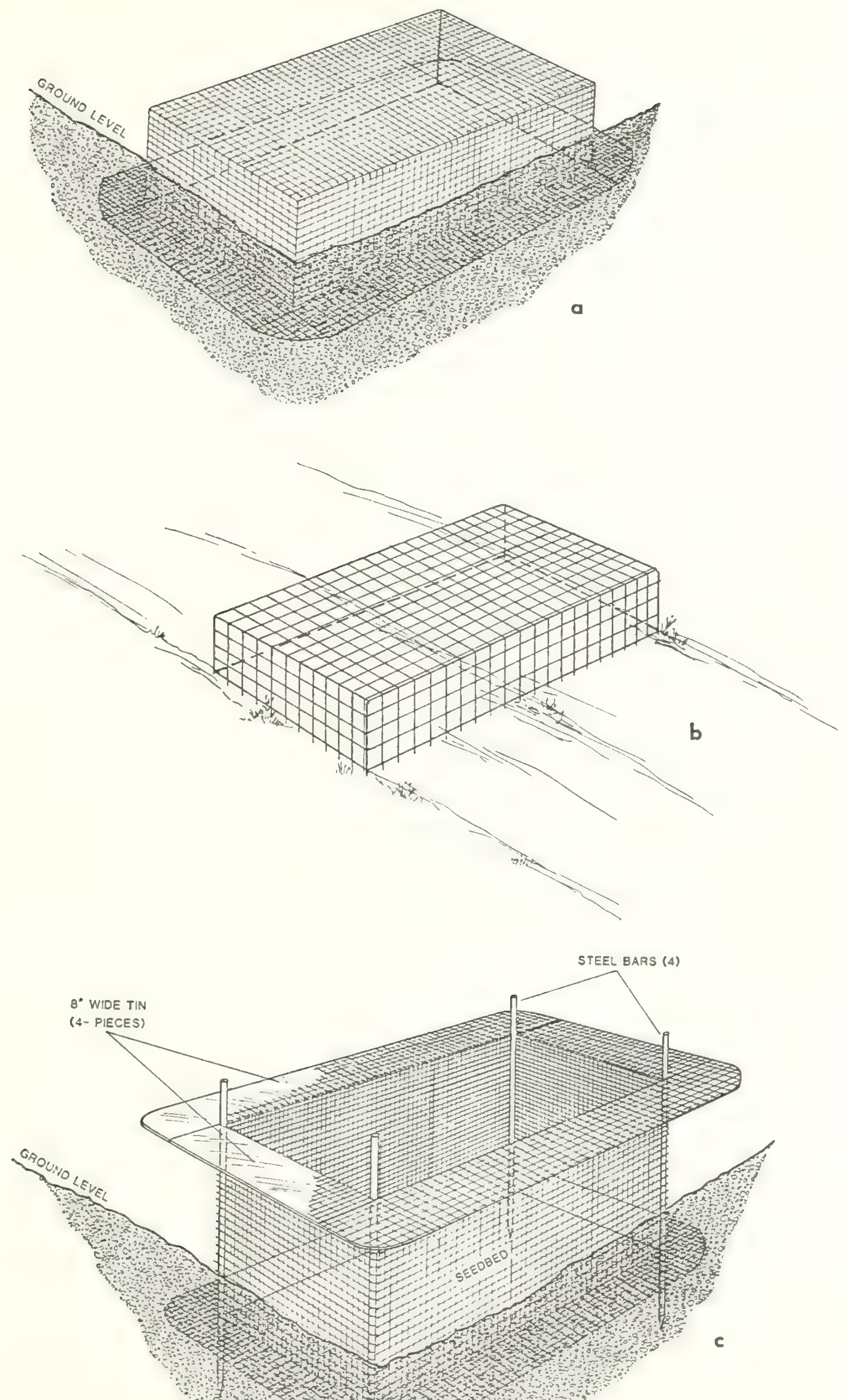

Figure 3—Cages for: (a) excluding birds and mammals, (b) excluding birds only, and (c) excluding mammals only.

Subsurface soil temperatures were measured with Taylor minimum-maximum thermometers at the same seedbed-shade plots where soil moisture collections were taken on replicates 1 and 3. Soil temperatures in replicate 2 were measured with temperature probes connected to electronic microprocessors designed for continuous collection of environmental conditions. Minimum and maximum soil temperatures were measured at a soil depth of 1 inch (the level where seeds were buried). Temperatures were measured and recorded weekly, daily, and sometimes hourly throughout the 1988 summer.

Maximum surface temperatures were measured weekly with wax (Big Three Industries-tempil) pellets, which melt at specific temperatures. Tempils used for this study were designed to melt at 100, 106, 113, 125, 138, 150, 163, 175, 188, and 200 °F. Tempils were placed on one of the mineral and litter seedbeds on each of the 0, 25, and 50 percent shade plots for a total of six plots on each replicate.

Data Analysis

The proportion of whitebark emergents on each subplot was used as the dependent variable for analysis of emergence differences between predator exclusion levels, shade levels, seedbed conditions, sowing depth, and factor interactions. Proportion of emergence is defined as the number of emergents divided by the number of seeds sown (40). Empty plots were counted as $1/4n$ $n = 40$ to prevent distortion of the analysis by small numbers (Mosteller and Youtz 1961). The transformation, arc sine of the square root of the proportion of germination, was used to stabilize variation due to proportions (Snedecor and Cochran 1980).

The statistical analysis system (SAS) was used to analyze whitebark pine emergence data. Analysis of variance was used to test for significance of main factors and interactions on seedling emergence and survival. Anova was also used for evaluation of soil moisture and temperature data. The "F" statistic was used to determine the significance of factors and their interactions on germination of whitebark pine. Tukey's standardized range test (Snedecor and Cochran 1980) was used to statistically test differences in emergence among factor levels. Unless otherwise stated references to significant results indicate the 0.05 level.

Predation on whitebark pine seed was analyzed separately from microsite factors affecting whitebark germination. Seed predation was assessed using results from the exclude birds only (EB), exclude no predators (EN), exclude rodents only (ER), and exclude birds and rodents (EA) treatments. The EA and ER treatments were used in analysis of variance to assess whitebark emergence differences between shade levels, seedbed conditions, and sowing depths.

SEED PREDATION

Birds and rodents were the two important predators on whitebark seed considered in this study. The Clark's nutcracker is considered the major bird species consuming whitebark seed. Chipmunks (*Eutamia* spp.), deer mice (*Peromyscus maniculatus*), and golden-mantled ground squirrels (*Spermophilus lateralis*) were assumed to be the main rodent consumers (Lanner 1980; Tomback 1981). Insects were considered a minor predator and were not seen feeding on or removing whitebark pine seed.

Surface-Sown Seed—Animals ate or removed 100 percent of surface-sown seeds on EB and EN treatments within 5 days after sowing. No seeds were removed from ER and EA treatments, indicating that birds were not randomly searching for whitebark pine seeds and screening effectively excluded rodents. Exclosures may have discouraged seed foraging by birds; however, birds, including the Clark's nutcracker, were observed sitting on exclosures of ER treatments and shade structures. No birds were seen foraging for seeds on any plots. Despite observations of birds sitting on the mammal-excluding cages, no seeds were removed from plots open to birds. It is assumed that surface-sown seeds on EB and EN treatments were eaten or removed by rodents while bird predation was, at best, minimal. Hutchins (1989) believes that random foraging by Clark's nutcrackers is highly unlikely since their efforts appear to be toward finding their own seed caches.

Buried Seed—Animal predation of buried whitebark pine seeds was evidenced by depressions on mineral soil and litter seedbeds at buried seed locations on all EB and EN plots. There was no evidence of disturbance at buried seed locations on ER treatments; therefore, it is assumed that there was no seed predation of buried seeds by birds. Seeds were untouched on EA treatments, indicating that rodent and bird predation was eliminated. Emergence from buried seeds occurred on EB and EN treatments, indicating that rodents did not find all available buried seeds. There was no significant difference in the mean number of whitebark emergents per plot between EB (0.67) and EN (0.86) treatments.

EMERGENCE

Emergence of whitebark pine was significantly affected by replicate, predator exclusion method, seedbed condition, and sowing depth (table 2). Four two-factor interactions showed significant relationship to whitebark pine emergence. Shading did not affect whitebark pine emergence.

Replicates—There were significantly fewer whitebark pine emergents per plot in replicate 3 (0.79) than in replicates 1 (3.08) or 2 (3.71) (table 3). This difference may be attributable to soil changes within the study area. Soil moisture in replicate 3 was nearly always less than in replicates 1 and 2 during the early summer when the emergence rate was highest (figs. 4 and 5).

The soil on replicate 3 was classified as a Typic Cryorthent, sandy skeletal with a 6-inch A horizon containing 54 percent sand over a C horizon of 60 percent sand. Soils on the other replicates have not been fully classified but appear to have a weak B horizon below a thicker A horizon indicating a different classification. Moisture may be the limiting factor for emergence on replicate 3 considering the high sand content of the soil profile and the shallow A horizon. The A horizon in replicates 1 and 2 was thicker and hand textural analysis indicated less sand and more silt and clay.

Table 2—Significance (Anova probability) of effects on seedling emergence of four treatments (predation, seedbed, sowing depth, and shade) and significant interactions. Before analysis, percent germination data were transformed by the arc sine of the square root (Snedecor and Cochran 1980). Analysis of variance results showing significance of biotic and microsite factors and two-way interactions of the arc sine transformation of the square root of germination proportion for the predator exclusion treatments, exclude rodents and birds and exclude rodents only

Source	DF	Mean square	F value	Significance
MAIN FACTORS				
*Rep*licate	2	0.1487	20.94	[1]*
*Pre*dator exclusion	1	.1648	23.20	*
*See*dbed condition	1	.0692	9.74	*
*Sow*ing depth	1	.7385	103.96	*
*Sha*de level	2	.0119	1.67	
INTERACTIONS				
Rep x Sow	2	.0656	9.23	*
Pre x See	3	.0335	4.72	*
Pre x Sow	3	.0530	7.46	*
Sha x See	2	.0255	3.59	*
Rep x Pre	6	.0058	.81	
Rep x Sha	4	.0029	.41	
Rep x See	2	.0039	.55	
Pre x Sha	6	.0165	2.32	
Sha x Sow	2	.0002	.03	
See x Sow	1	.0001	.02	
Error	45	.0071		

[1]* indicates significance at the 0.95 confidence level.

Table 3—Mean number of emergents per plot by replicate, predator exclusion, shade level, seedbed condition, and sowing depth on plots excluding rodents and birds (EA) and excluding rodents only (ER)

Replicate	Mean	Predator exclusion	Mean	Shade level	Mean	Seedbed condition	Mean	Sowing depth	Mean
				Percent					
1	[1]3.08 (a)	EA	3.69 (a)	0	1.96 (a)	Mineral	3.17 (a)	Surface	0.50 (a)
2	3.71 (a)	ER	1.36 (b)	25	3.04 (a)	Litter	1.89 (b)	Buried	4.56 (b)
3	0.79 (b)			50	2.58 (a)				

[1]Similar and dissimilar letters in parentheses represent nonsignificant and significant differences respectively.

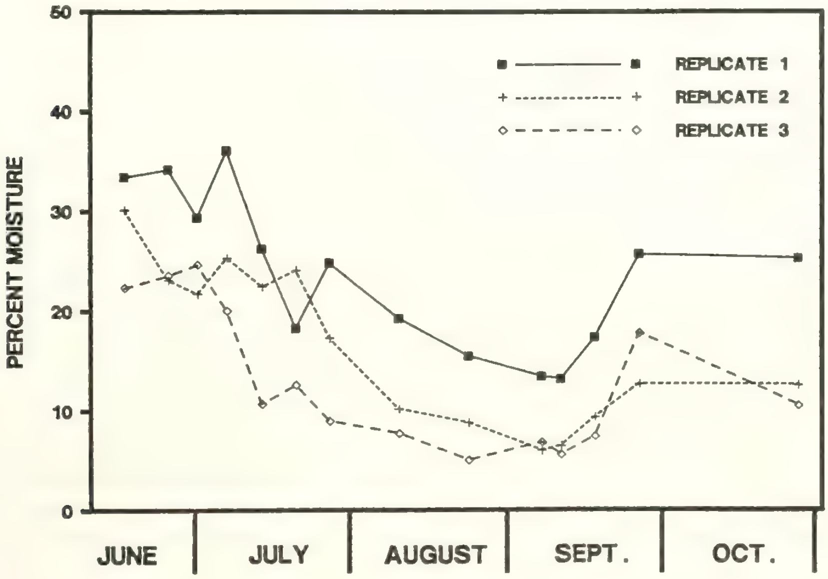

Figure 4—Percent moisture in top 2 inches of soil by replicate.

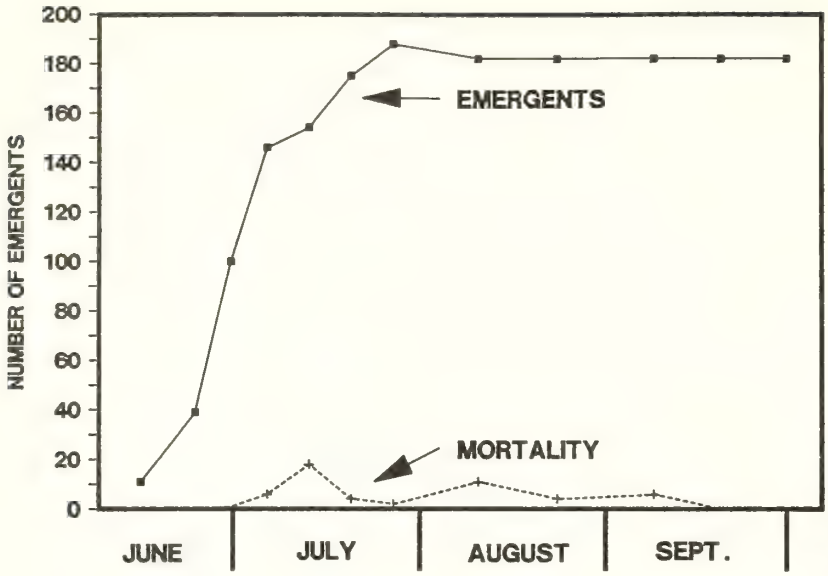

Figure 5—Total number of living emergents and current deaths of whitebark pine over time—1988. The data include germinants from all predator exclusion methods, shade cover levels, seedbed conditions, and sowing depths.

Predator Exclusion—Whitebark pine emergence was significantly affected by screen design differences between the EA and ER treatments (table 2). The mean number of seedlings per plot was 3.69 for EA treatments and 1.36 on ER treatments (table 3). The difference in emergence between the EA and ER treatments can probably be attributed to within-plot microclimate differences. The EA treatment had hardware cloth with 0.25-inch-square holes about 4 inches above the ground level and totally enclosing the plot. The metal cloth may have provided extra shade-reducing daytime temperatures; the overtopping of the screen may have increased night temperatures. A subsample of each treatment combination will be monitored in 1989 for soil temperature and solar radiation differences.

Seedbed Condition—Seedbed condition significantly affected whitebark pine germination throughout the summer (table 2). There was an average of 3.17 germinants per plot on mineral soil seedbeds versus 1.89 on litter by the end of the summer.

Most conifers germinate best on mineral seedbeds (Seidel 1979; Zasada and others 1978). When mineral soil is exposed to eliminate competing vegetation, more light, moisture, and nutrients are available for seedling growth (Schmidt and others 1976). Although no quantitative measure of competing vegetation was taken, reduction of competition may be the reason for better germination of whitebark pine on mineral seedbeds.

Sowing Depth—Sowing depth significantly affected regeneration of whitebark pine on plots (exclude rodents and birds and exclude rodents only) where seed was protected from animal predation. Emergence from buried seed was significantly higher (4.56 emergents per plot) than from surface-sown seeds (0.50 emergents per plot) (table 2).

There are no documented studies on germination differences between various sowing depths of whitebark pine seed. Most conifer seeds germinate on the surface following wind dispersal. The Clark's nutcracker caches whitebark pine seed at a depth of 1 to 1½ inches on a variety of ground surfaces such as mineral soil, litter, and gravel (Lanner 1980). Germination of buried seeds appears to be the evolved regeneration method of whitebark pine (Tomback 1983).

Shade Cover—Shade was not a significant factor affecting emergence of whitebark pine seed (table 2). Germination of whitebark pine was generally higher for shaded than nonshaded treatments, ranging from 3.04, 2.58, to 1.96 germinants per plot with 25, 50, and 0 percent shade cover, respectively (table 3). Whitebark pine is rated intermediate to intolerant of shade (Arno and Hoff 1989). The shade created by the shade coverings is dead shade. The slats of the snow fence cause alternate strips of shade and full sunlight. This type of dead shade may not be enough, even at the 50 percent shade cover level, to affect emergence. A better measure of individual plot shading will be examined in 1989 with solar radiation monitoring.

INTERACTIONS

Four two-factor interactions of microsite variables significantly affected whitebark pine emergence (table 2). The interactions were replicate by sowing depth, predator exclusion by seedbed condition and by sowing depth, and shade cover by seedbed condition (fig. 6). The replicate by sowing depth interaction showed similar trends for all replicates; however, replicate 3 showed a steep reduction in the absolute difference in mean number of emergence per plot between buried and surface-sown seed (fig. 6a). Few buried seeds emerged and no seeds emerged on the surface. This change in absolute difference may be attributed to soil-moisture variation in replicates as described earlier.

The interaction of predator exclusion treatment by seedbed condition showed less absolute difference in mean number of whitebark pine emergents per plot between mineral and litter seedbed under the ER treatment

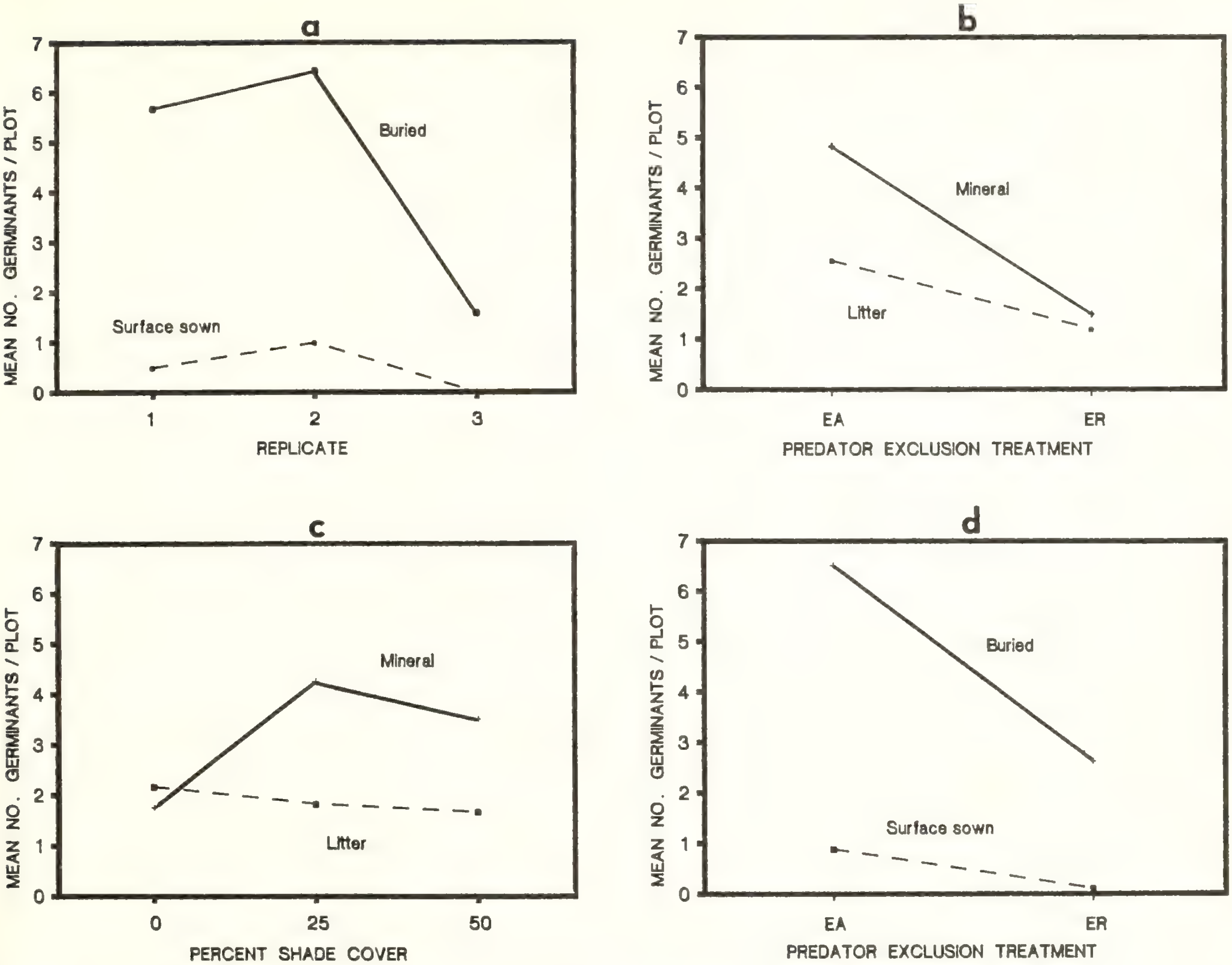

Figure 6—Mean number of whitebark pine germinants per plot for analysis of variance interactions: (a) replicate by sowing depth, (b) predator exclusion treatment by seedbed condition, (c) percent shade cover by seedbed condition, and (d) predator exclusion treatment by sowing depth.

(fig. 6b). The change in absolute values may be caused by microclimate differences between predator exclusion treatments due to effects of metal screen exclosures. Increased measures of microsite differences in 1989 may help explain this interaction of predator exclusion treatment and seedbed condition.

Shading was not a significant factor affecting whitebark pine emergence, but the interaction of shading and seedbed condition was (table 2). There were significant differences in emergence between mineral and litter seedbeds under 25 and 50 percent shade cover, but not at 0 percent shading (fig. 6c). This indicates that shading as little as 25 percent improves whitebark emergence on mineral soil; however, no shading level significantly affected emergence on litter seedbeds.

The predator exclusion treatment by sowing depth also showed less absolute differences in mean number of whitebark pine emergents per plot between buried and surface-sown seeds under the ER treatment (fig. 6d). Screening differences between predator exclusion treatments may again be the reason for the absolute value changes.

MORTALITY

Whitebark pine emergence rates were high from mid-June through the end of July, slowed, and then leveled off in August (fig. 5). Germinants continued to emerge until the first of September, but total number of survivors remained about the same because of compensating mortality.

Mortality of whitebark pine emergents did not begin until the first of July and continued at a low level until the first of September (fig. 7). Two causes of mortality were identified: (1) insolation (indicated by scorching of seedling stem at ground surface), and (2) drought. Animal, fungi, and insect mortality were not apparent

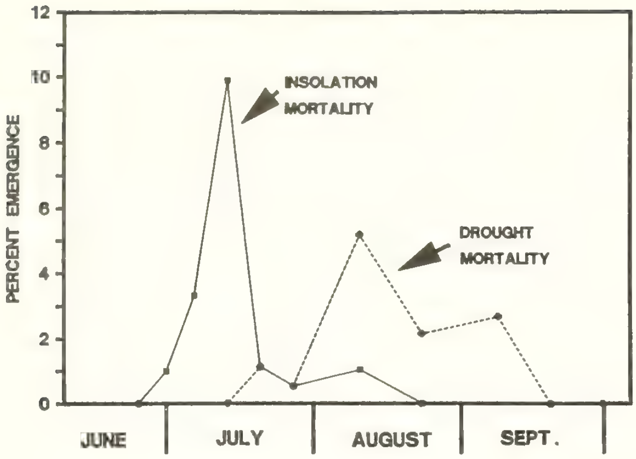

Figure 7—Percent insolation and drought mortality of whitebark pine seedlings over time—1988. Percent mortality represents the percent of living seedlings that died in the period.

on any of the whitebark seedlings examined. Insolation mortality of seedlings began early in the season when day lengths were the longest and ended by early August (fig. 7). Insolation-caused mortality was highest on nonshaded mineral seedbeds; these beds also had the highest absolute (98 °F) and highest mean (78 °F) subsurface temperature. Drought mortality began around the third week in July and continued until the first of September.

Twenty-five and 50 percent shade cover reduced total seedling mortality (table 4). Total mortality did not vary with shade level; however, shading greatly influenced the mortality type for whitebark pine seedlings on mineral and litter seedbeds. Insolation mortality of seedlings was highest on mineral and litter seedbeds with no shade cover; shading of as little as 25 percent greatly decreased insolation mortality (table 4). Because shading reduced soil moisture (fig. 8), we tentatively attribute its effect to reduction of soil temperature. Our explanation is apparently countered by the relatively warm temperatures observed on littered soils receiving 50 percent shade.

Table 4—Mortality of whitebark pine emergents on mineral and litter seedbeds under 0, 25, and 50 percent shade. Mortality is the percent of emergents in each category that died (212 total germinants)

Percent shade cover	Seedbed condition	Hypothetical mortality cause		
		Insolation	Drought	Total
		- - - - - - - - - -Percent- - - - - - - - - -		
0	Mineral	33	11	44
	Litter	23	6	29
25	Mineral	6	8	14
	Litter	0	29	29
50	Mineral	5	12	17
	Litter	9	22	31

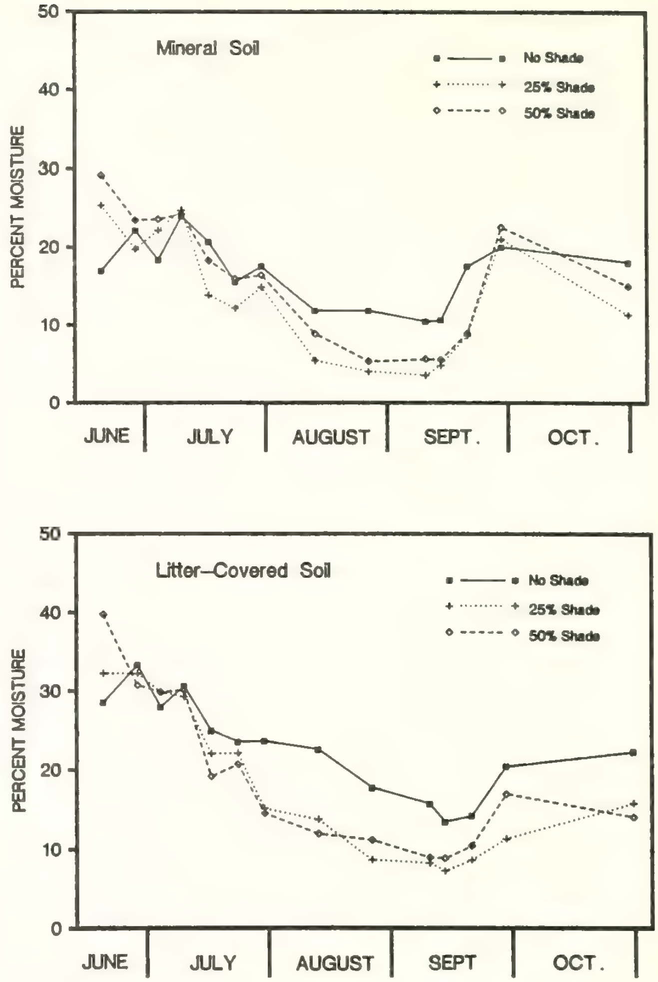

Figure 8—Percent moisture in top 2 inches of soil on a mineral and litter seedbed.

Drought mortality of whitebark pine seedlings was lowest on nonshaded plots. This is consistent with the fact that nonshaded plots were moister than shaded plots during the mid-summer weeks when most drought mortality was occurring (fig. 8). Low canopy catch may account for higher soil moisture values on open plots.

SOIL TEMPERATURE AND MOISTURE

Regardless of shading, surface temperatures were higher on litter seedbeds than mineral soils under 0, 25, and 50 percent shade cover (table 5). Surface temperatures were higher on litter seedbeds possibly because of increased light reflectance off light-colored needles and because of an insulating effect reducing downward heat transmittance.

Minimum subsurface temperatures were warmer with increased shade cover, indicating a moderating effect of screening on temperature (table 6). Mineral seedbeds had relatively low minimum temperatures and high maximum temperatures; litter mulch moderated soil temperature.

Table 5—Maximum surface temperatures recorded on mineral and litter seedbeds under 0, 25, and 50 percent shade cover

Seedbed condition	N	Percent shade cover 0	25	50
		°F		
Mineral	3 x 6	150	138	138
Litter	3 x 6	163	150	163

Table 6—Minimum-maximum soil temperatures at a depth of 1 inch on mineral and litter seedbeds under 0, 25, and 50 percent shade cover. Values without parentheses are June through September absolutes. Values in parentheses are mean minima and maxima for the summer

Seedbed condition	Temperature	Percent shade cover 0	25	50
		°F		
Mineral	Minimum (Mean min)	11 (34)	17 (37)	19 (33)
	Maximum (Mean max)	98 (78)	83 (68)	84 (73)
Litter	Minimum (Mean min)	16 (35)	18 (35)	20 (35)
	Maximum (Mean max)	81 (73)	75 (67)	82 (69)

Soil moisture decreased steadily from mid-June through mid-September and rose again with late September rains (fig. 8). Soil moisture remained highest on unshaded plots on mineral and litter seedbeds; this may be due to interception or deflection of rain by shade covers. There was little difference between plots shaded to either 25 or 50 percent.

A typical September storm (Weaver 1989) partially replaced soil moisture. Soil moisture declined again in late September to early October on mineral seedbeds but increased slightly on litter seedbeds. The increase in soil moisture in September indicates that small amounts of precipitation fell during that time and litter had a positive effect on holding that moisture.

SUMMARY

Rodents are the main predators of whitebark pine seed when it is available on the forest floor or buried. All surface-sown seeds were eaten or carried off when rodents had access to them. Nearly all accessible buried seeds were eaten or removed; however, some did germinate. Seeds available only to birds were undisturbed, indicating no open foraging for seeds by avian predators. Birds were seen sitting on several exclosures, but none were seen foraging for seed inside exclosures open to birds. All seeds were undisturbed and able to emerge on treatment plots that excluded all predators and excluded rodents only. Emergence was highest for treatments excluding all predators, probably due to microclimate changes caused by the exclosure structure. The overtopping screen probably modified the microsite climate by holding heat in during the nights and reducing daytime temperatures.

Emergence of whitebark pine seeds was slightly higher on shaded plots. Emergence was highest on the 25-percent and second highest on the 50-percent shade cover plots. It is unknown why emergence was highest on the 25-percent shade cover plots. Perhaps whitebark pine seeds need some shade (25 percent) for setting up the proper conditions for germination; too much sun or shade (0 to 50 percent) may be detrimental.

Emergence of whitebark pine was significantly higher on mineral than on litter seedbeds. This was highly evident for treatments protecting seeds from all predators and may be confounded by the shading effect from the exclosure structure. Emergence was significantly higher on shaded-mineral than on shaded-litter seedbeds. There was no difference in emergence between seedbed types under open conditions.

Sowing depth of seed had the greatest influence on emergence of whitebark pine. Emergence of buried seeds was significantly higher than that of surface-sown seeds when seeds were undisturbed and available to germinate (fig. 7). Surface germination of whitebark does occur when seeds are undisturbed but is highly unlikely because of near-complete seed loss due to small-mammal foraging. Mammals took or consumed most buried seeds on plots where seeds were available to them; however, some seeds were missed and did germinate. Mammals would probably not have found as many buried seeds, increasing the number of emergents, had surface-sown seeds not been in close proximity acting as an attractant.

Mortality of whitebark pine emergents varied by cause throughout the summer. Insolation mortality was highest in early July but was not a factor after early August. Insolation mortality was highest on mineral seedbeds under no shade even though surface temperatures were highest on litter seedbeds. Drought mortality was highest during August and September when soil moisture was lowest. Drought mortality was highest on litter seedbeds under shaded conditions where soil moisture was the most limiting.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from Ken Gibson)—Though we haven't studied insect predation in whitebark pine to a great extent, it has been observed. Did you notice any in your studies? If so, was it significant?

A.—Of the seed that was surface sown and protected from large predators 99 percent was still visible after 1 year. The 1 percent that was missing was on litter seedbeds and could have been removed due to insect predation, although I did not see that. I was attributing the missing seed to the possibility that from snow and rain they had fallen down through the litter and were no longer visible. I did not want to disturb the sites for fear of disrupting germination.

Q. (from Mike Merigliano)—Did you account for the possible heat retention effect of the animal barrier and sun shade screens on seedling survival?

A.—I assumed the sun shade screen would hold some heat similar to that of what an overtopping tree crown would. I did not expect the screening, because of its open nature, to cause much of an effect. Obviously, the screening that completely enclosed some plots was having a substantial effect on heat retention. This coming summer I will be looking at this in more detail.

Q. (from Ray W. Brown)—What is known about pH limits of whitebark pine, and its tolerance to low pH during germination?

A.—I do not have an answer to this question. I have not seen literature referring to this subject. This would be a perfect laboratory experiment that could be done very quickly.

Q. (from Harry Hutchins)—What influence do you feel your enclosures and your scent have on attracting rodents to your caches?

A.—The enclosures likely have a great influence on attracting rodents because if they found seed there they would likely key on this point and check out all the enclosures. My scent would probably also be an attractant to rodents because of their natural curiosity. I am not sure how you could effectively test the influence of human scent as an attractant.

STAND DEVELOPMENT IN WHITEBARK PINE WOODLANDS

T. Weaver
F. Forcella
D. Dale

ABSTRACT

Analysis of density data from stands in the Northern Rocky Mountains shows that, while seedlings establish at the rate of over 1,000/ha x year in whitebark pine-grouse whortleberry (Pinus albicaulis-Vaccinium scoparium) *forests of all ages, stem numbers in the canopy thin to 400 at 30 years, 150 at 200 years, and 100 at 300 to 600 years. Indices of productive potential, cover, and total circumference rise to an asymptote at about 100 years. Total basal area rises from 0 to 60 m^2/ha at about 200 years, the aggregate basal area of trees with diameters over 20 cm rises from 0 to 40 m^2/ha at about 250 years, and tree height maximizes (12 m) at 200 years. It is hypothesized that further growth in productive potential (that is leaf and/or root area) is prevented by limited supplies of water or a nutrient, further growth in basal area is prevented by lack of a nutrient (probably not carbon, hydrogen, oxygen, or nitrogen) and further growth in height is prevented by scarcity of water.*

INTRODUCTION

Ecologists often describe plant succession by comparing communities existing on a series of sites that are considered environmentally identical, but differ widely in age (Boggs and Weaver, in preparation; Cooper 1923; Cowles 1899; Crocker and Major 1955; Olsen 1958). Chronosequence studies in secondary seres in the whitebark pine-grouse whortleberry (*Pinus albicaulis-Vaccinium scoparium*) environments (= habitat types or HT's, Arno and Weaver, this proceedings; Pfister and others 1977; Weaver and Dale 1974) have demonstrated little change in understory vegetation (Weaver and Dale 1974), large increases in biomass (Forcella and Weaver 1977), and small increases in productivity (Forcella and Weaver 1977, 1986). Field data from these studies are reworked here to (1) describe the dynamics of tree establishment, stand closure, and competition and (2) to generate hypotheses to explain the control of productivity, maximum standing crop, and tree height.

METHODS

To characterize succession in whitebark pine woodlands we compared 47 stands of diverse ages in one environmental type (*Pinus albicaulis-Vaccinium scoparium* [Daubenmire and Daubenmire 1968; Pfister and others 1977]). Each stand was aged by coring three trees representative of the dominants, that is, trees that were neither new reproduction nor representatives of an earlier generation; the ages ranged from 29 to 643 years. The stands sampled were broadly representative of stands found in Montana, Wyoming, and Idaho (Forcella 1978; Forcella and Weaver 1977; Weaver and Dale 1974).

Tree densities were estimated by counting individuals in representative areas at each site. Trees in the 19 stands considered in the first study (Weaver and Dale 1974) were sampled with a 500-m^2 circular plot (r = 12.6 m). To guarantee a complete count, we counted seedlings in a 1- by 30-m plot whose center coincided with that of the circle. Trees and seedlings in the 28 stands sampled in the second study were counted in a 600-m^2 area consisting of three 6.67- by 30-m plots (Forcella and Weaver 1977).

Trees in the first and second studies were tallied into 10-cm and 5-cm diameter at breast height (d.b.h.) classes, respectively. These data were used directly in comparison of seedling survival among stands of differing age. Total circumferences were calculated by assuming that all trees in a size class had a diameter equal to the midpoint of the class, multiplying for each individual ($\pi \times D$), and summing across individuals. The use of midpoints introduced a downward bias in the smallest size classes in a stand and an upward bias in the largest size classes. Calculation of total basal areas also involved the use of midpoints, multiplication ($\pi \times r^2$), and summation across all trees in the plot. We did not correct for the additional small error due to the fact that the basal area of a midpoint tree is less than the average basal area of trees at the top and bottom of that size class.

Canopy cover was estimated as the percentage of 30 points, observed overhead through a vertical periscope (Weaver and Dale 1974), which were covered by trees. Tree heights were measured with a Bitterlich "relaskop."

Cone production in the year of observation was estimated by multiplying an estimate of branch tip density

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in the canopy (#/m^2) by the average number of cones on a sample of branch tips. Cone production in earlier years was estimated by multiplying branch tip density by estimates of cone production made from counts of cone scars at nodes representing the previous 4 years (Weaver and Forcella 1986). Seed production was estimated by multiplying cone number by the average number of seeds in a cone (75 ± 28, Weaver and Forcella 1986).

RESULTS AND DISCUSSION

The dynamics of *Pinus albicaulis* in whitebark pine woodlands were studied by examining a chronosequence based on 47 stands with ages ranging from 29 to 650 years. Readers preferring different units will remember that there are 10,000 m^2/ha and 2.47 acres/ha.

Seedling Establishment

Cone production rose from 0 cones/ha in newly established stands to an average of about 10,000 cones/ha in stands over 100 years old. Figure 1a presents 5-year averages of cone production. Cone production was variable among stands (for example, 0.5 to 5 cones/m^2 annually in the 100- to 200-year stage) as well as among years (Weaver and Forcella 1986). If each cone contained 75 seeds (Weaver and Forcella 1986), seed production ranged from 370 to 3,700 seeds/ha annually in stands over 150 years old.

Median seedling density was 1,000 to 1,500 seedlings/ha during the first 300 years of stand development (fig. 1b) and quite variable among stands in any age class (for example, 0 to 5,000 among 100- to 200-year communities). The large seedling number in young stands must be due to long distance dispersal, probably by Clark's nutcracker (Hutchinson and Lanner 1982; Linhart and Tomback 1985), because whitebark pine seeds are both too heavy for wind dispersal and unlikely to have survived in the seed bank since the stand replacing event (Harper 1977). The consistency of seedling densities across stands of increasing age suggests that nutcracker cache density may not vary significantly among stands with different ages.

Competition and Thinning

Total whitebark pine density falls exponentially from 4,000 individuals/ha at 30 years to 1,500 at 200 years and 1,000 at 400 years (fig. 1d). We attribute this decline to self-thinning; while seedlings established with mean areas of 2 to 3 m^2 cannot compete significantly, 200- to 300-year-old trees apparently require mean areas averaging about 10 m^2. The decline in tree density with time is exponential because the growth of young trees is exponential and the area saturated by a tree is proportional to its size.

Seedling fate is a second indicator of the time of resource (that is, space) saturation in developing whitebark pine woodlands. Seedlings establish at rates of 1,000 to 1,500 individuals/ha^2 in stands of all ages (fig. 1b).

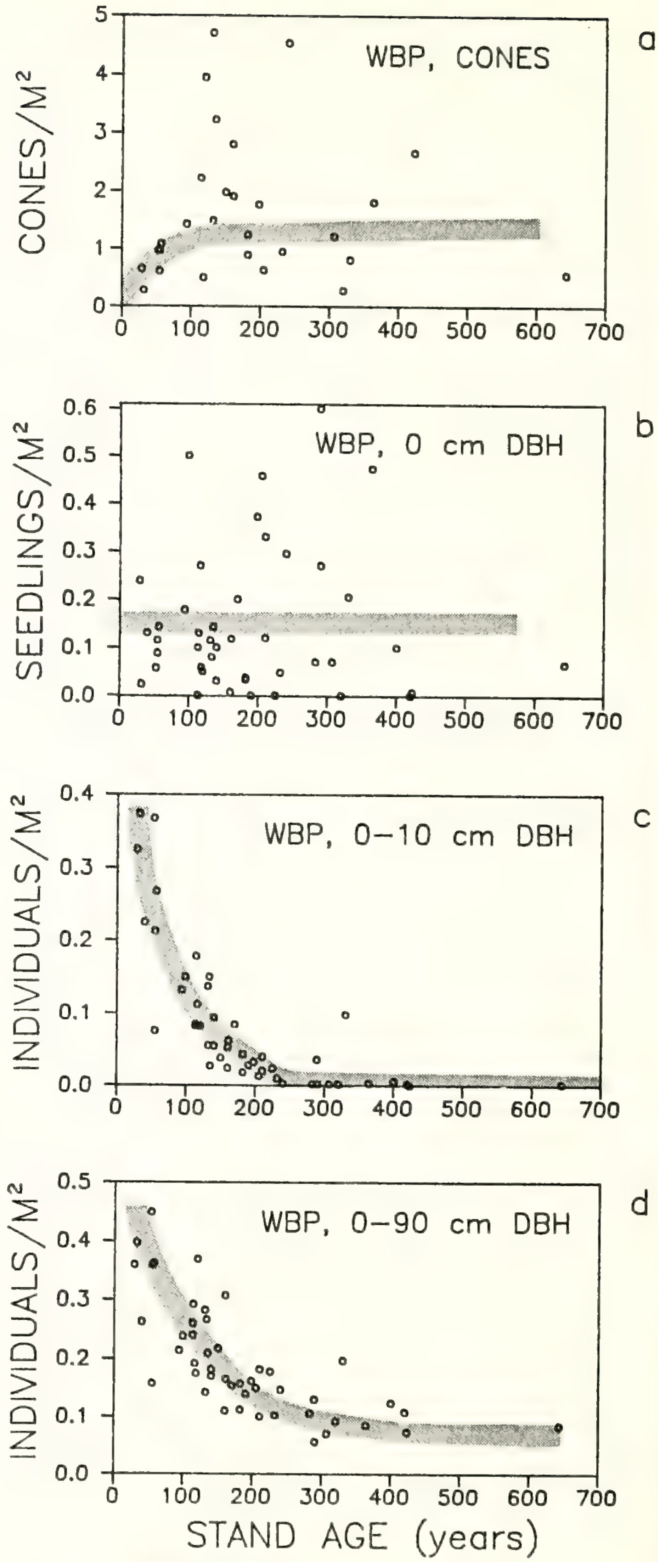

Figure 1—Change in whitebark pine density with stand age (0 to 650 years): (a) cones with an average of 75 seeds, (b) seedlings, (c) 0- to 10-cm d.b.h. saplings, and (d) all individuals. While seedling number remains constant, establishing trees (0 to 10 cm d.b.h.) fail in stands older than 250 years, established trees self-thin through 350 years. The line is hand-fit through medians calculated across centuries.

In stands less than 100 years old many individuals reach heights of 1.5 m, as indicated by tree counts in the 0- to 5- and 0- to 10-cm d.b.h. classes (fig. 1c). The simultaneous presence of seedlings and absence of 0- to 5-cm (and 0- to 10-cm) d.b.h. trees in stands older than 150 (250) years indicates that, while there are noncompetitive "safe sites" for seedlings in all stands, the "safe sites" in stands older than approximately 100 years are not large enough to support growth from the seedling to the sapling stage. Since the probability of reproductive success is diminishingly small for those seedlings that regularly establish in clearings of less than 10 m^2, we conclude that the sites are, in fact, only apparently "safe." That is, tree establishment is only apparent and its appearance is an artifact of the short time period humans easily comprehend.

The sum, across all trees in the stand, of tree circumference is a third indicator that resource use becomes complete in most whitebark pine woodlands at about 100 years. Circumference is a good index of leaf area because it is strongly correlated with the amount of vascular tissue supplying water and nutrients to the leaves (Marshall and Waring 1986; Shinozaki and others 1964). It must be an equally good index of root area because it is strongly correlated with the amount of phloem delivering photosynthate to absorbing organs. Whether saturation is due to canopy closure (full utilization of light) or complete

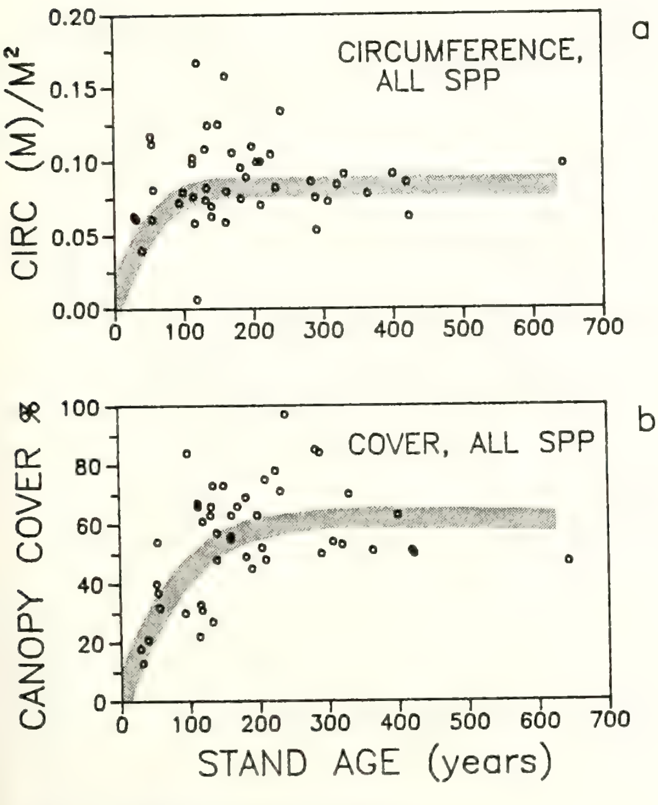

Figure 2—Indices of resource saturation and productive potential (a) aggregate circumference and (b) canopy cover increase to about 150 years and equilibrate there. The line is hand-fit through medians calculated across centuries.

exploitation of the soil resources (water and minerals), we can expect total circumference to grow exponentially (or, at least linearly) from stand establishment to near site saturation and then level out. Our expectation is realized (fig. 2a): initial circumference (even under very high seedling densities) is near 0, rises to about 750 m/ha (= 0.1 m/m^2) soon after 100 years, and remains constant through the next 500 years. Regardless of whether the population is light or water-nutrient limited, growth of one individual after saturation (100 years in whitebark pine) can only occur when resources are released by the death of another individual (Valentine 1988).

Factors Limiting Production

Community production can be limited by resource availability. Among resources, lack of heat (temperature) surely limits production in the winter through its influence on both water-nutrient availability and enzyme activity. Warmer and moist conditions may result in nutrient limitation in the spring (Weaver and Forcella 1979), and relatively dry conditions probably cause water limitation in the summer (Weaver 1980).

The productive potential of a community also depends on its "factory size"—its leaf or root area. Factory size might be limited by either light or a soil (water or a nutrient) resource. While the former is often assumed (and as a result, trees are often ranked according to their "shade tolerance"), ditching tests suggest that root competition is often the actual controlling factor (Watt and Fraser 1933). Whitebark pine woodlands consist of open stands with an initial canopy cover of 0 percent, which grows to a limit of 60 percent in 100 to 150 years, and remains constant at that level for the next 200 to 300 years (fig. 2). Since, in saturated stands, canopy coverages are only 60 percent and since forest floor light levels (200 to 1,600 $uEm^{-2}s^{-1}$) are well above those required for whitebark pine photosynthesis (200 $uEm^{-2}s^{-1}$ at compensation and 1,000 $uEm^{-2}s^{-1}$ at saturation, Jacobs and Weaver [this proceedings]), we deduce that stand saturation in whitebark pine is more likely due to complete exploitation of a soil resource (water or a nutrient element) than to exhaustion of the light supply.

Factors Limiting Maximum Standing Crop

The rate of production is initially low, grows with increases in foliage cover, and halts at stand saturation (about 100 years), because leaf or root surfaces are maximized. In contrast, basal area accumulation continues to a maximum (60 m^2/ha) at 200 to 250 years and levels there (fig. 3a). The upper limit for standing crop must be due to one of three factors: excessive respiratory mass, a resource limit, or a structural limit. First, the most immediate limiting factor is probably the accumulation of a respiratory mass sufficient to consume all current photosynthesis (Odum 1969). Second, since the canopy is not saturated at maturity, however, the ultimate limiting factor must be either a nonlight resource or a structural deficiency. The limiting factor cannot be temperature

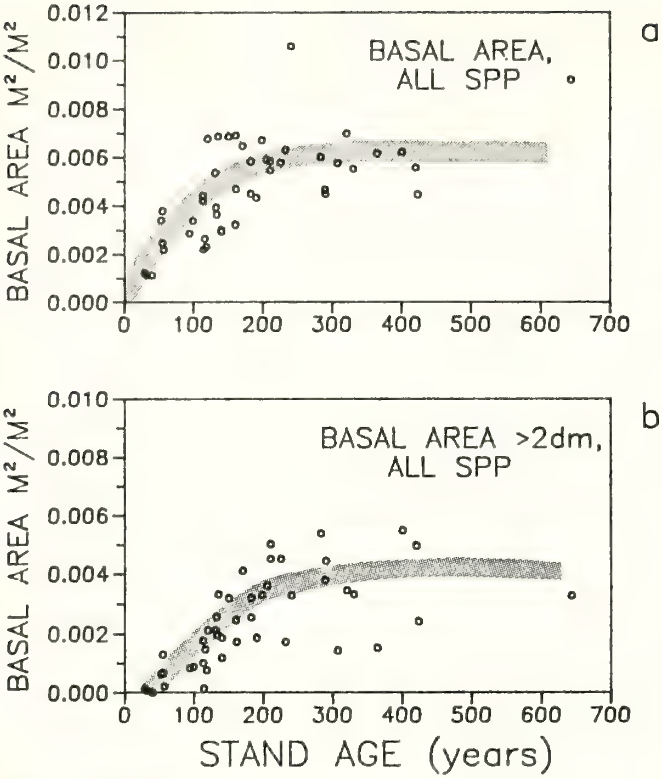

Figure 3—Standing crop, indexed by basal area (a) total and (b) trees larger than 20 cm d.b.h., increases to about 250 years and equilibrates. Tree heights equilibrate at about 200 years (12 M, Weaver and Dale 1974). The line is hand-fit through medians calculated across centuries.

because air temperature does not change systematically during stand development and, while soil temperature might be reduced by canopy shading, if this effect were controlling it should be maximized at canopy closure (100 years, not 250 years). The limiting factor cannot be water, because, while drought may stop growth each summer, precipitation in the following winter and spring will allow resumption of growth (not observed) if no other factor limits. The limiting resource is most likely the supply of an important nutrient—and probably not carbon, hydrogen, oxygen, or nitrogen, because supplies of these elements are constantly delivered from the atmosphere. The reader may question the inclusion of nitrogen in the list of elements available from the atmosphere; we do so because we believe researchers underestimate both nitrogen losses (production of decomposition-recalcitrant organic matter, and fire) and compensating nitrogen imports (Aradottir 1984; Boggs and Weaver, in preparation; Johnson and others 1983; Weaver and others 1978). Third, a structural limit would exist if nutrient supplies were sufficient to allow the growth of larger trees with the consolidation of more productive potential, but physical damage prohibited it. We doubt that it is physical control because the trees in whitebark pine woodlands can be relatively large, because little wind deformation occurs, because wind-snow breakage is uncommon, and because seedlings occupying openings fail to establish.

Total biomass depends on tree height as well as basal area. Tree heights increase linearly to 12 m at 200 years and then level off (Weaver and Dale 1974). Maximum tree height is most likely determined by water availability at the shoot tip and is therefore a product of the drying power of the air, the conductivity of the stem, and the water supplying power of the soil.

Harvestable Production

With few exceptions (Losensky, this proceedings), the height and form of whitebark pine trees encourage the reservation of forests dominated by it for wildlife, watershed cover, recreational, and esthetic purposes rather than timber production. If logging is contemplated, the manager needs a measure of basal area against time for trees large enough to log (for example, over 20-cm d.b.h.). Figure 3b shows that the basal area of trees large enough to log levels later (about 250 years) and at a lower value (40 m^2/ha) than total basal area.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from R. Brown)—Do you know of studies of water relations—for example, the diurnal course of plant water status or transpiration rates—for whitebark pine?

A.—While Tranquillini (1979) provided extensive discussion of water relations in closely related *Pinus cembra*, I know of no studies of water relations in whitebark pine. In this paper I have speculated that water stress limits late summer production, but not maximum standing crop, in whitebark pine woodlands. In answering your question (of my climate paper) about factors limiting the distribution of whitebark pine I speculated that the southern limit of the tree's range might be set by summer drought.

Q. (from M. Cole)—According to your basal area graphs, standing crop is initially zero and increases asymptotically with time. The graphs also show considerable variance. Do you think the variance could be explained by plotting a series of site class curves in each graph?

A.—The variance you observe strongly suggests that while we selected stands representative of the *Pinus albicaulis-Vaccinium scoparium* woodland climax there is "site class" variance in the indicated habitat type. While it would be well represented by site class curves, I have no independent site class data to enable me to draw such curves; can you suggest an approach I haven't thought of?

OCCURRENCE OF MULTIPLE STEMS IN WHITEBARK PINE

T. Weaver
J. Jacobs

ABSTRACT

Depending on the stand, Montana-Wyoming whitebark pines (Pinus albicaulis) *may have multiple stems in 8 to 79 percent of the trees. The clumps had one to 11 stems with stand medians between two and three. Multiple stems may arise from several seeds germinating together, from basal branching, or both. Median stem number and maximum stem number per clump decrease with stand age, probably due to both within-clump and between-clump competition. While declines are slight in open woodlands, clumps almost disappear in closed forests. The presence of clumps is correlated with stand density in other conifers as well.*

INTRODUCTION

While most trees tend to be single stemmed, a few (such as *Quercus*, *Populus*, *Salix*, and *Sequoia*) are often multiple stemmed (Elias 1980). Stem number in trees must be determined by two factors: (1) the tendency to form, at one point, stems that are genetically identical (from, for example, spontaneous basal branching or wound-induced branching), maternally related (poly-embryony or seeds cached from one tree), or less strongly related (seed cached from different trees) individuals and (2) the tendency of multiple stems to survive at that point.

Whitebark pine (*Pinus albicaulis*) has long been noted for its tendency to occur in clumps with stems fused, or not fused, at the base (Harlow and Harrar 1958; Sudworth 1908). Multiple-stem origin (factor 1) was originally attributed to branching (Sudworth 1908), then to branching and/or seed caching (Weaver and Dale 1974), and most recently almost exclusively to seed caching (Lanner 1980; Linhart and Tomback 1985). The importance of stem survival (factor 2) in the determination of the number of stems in a clump has received little attention. The objectives of this note are to demonstrate the multiple-stem phenomenon for the whitebark pine of subalpine woodlands, to examine evidence for the mode of multistem initiation, and to open discussion on the effect of survival of the stems in a clump.

Paper presented at the Symposium on Whitebark Pine Ecosystems: Ecology and Management of a High-Mountain Resource, Bozeman, MT, March 29-31, 1989.

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METHODS

Clump sizes were observed in 19 stands located in 10 subranges of the Rocky Mountains between latitude 43.5° and 46.5° N. All stands were subtimberline woodlands with canopies dominated by whitebark pine and understories dominated by grouse whortleberry (*Vaccinium scoparium*); none of the stands was krummholz. In each stand, the number of stems was counted on each tree in a representative 500-m^2 (12.6-m [41.3-ft] radius) circular plot. The stand was aged by coring three representative dominant trees. Canopy cover was estimated by determining, with a periscope, the percentage of 33 points that was covered. The locations, climate, soils, and vegetation of the study areas, as well as the sampling methods, are described in greater detail by Weaver and Dale (1974).

The 52 seedlings observed for basal branching were planted one-seed-per-pot and grown under normal nursery conditions for 2 years. The seeds were collected just north of Yellowstone National Park in the Palmer Creek-Bear Creek drainage at an altitude of 2,677 m (8,700 ft).

THE PHENOMENON

Observations in 19 woodland stands—neither krummholz nor forest stands—in the Rocky Mountains between latitude 43.5° and 46.5° N. (table 1) support five descriptive statements about clumping in whitebark pine.

1. There were both single-stemmed and multiple-stemmed trees in every stand.
2. There were more multiple-stemmed than single-stemmed clumps in 37 percent of the stands.
3. Clumps with more than seven stems were rare in stands over 150 years old. The fact that the smaller stems in older clumps were often dead suggests that weaker associates were competitively excluded (Lanner 1988).
4. Over half of the clumps were multiple stemmed in stands with cover less than 48 percent and less than half the clumps were multiple stemmed in stands with cover greater than 60 percent. Competition associated with stand closure probably selected against stems in clumps, since competition from the time of establishment would give clumped stems a relatively small height and would allow them to be overtopped and outcompeted by trees outside the clump.
5. These forest trees had one to 11 stems with a median averaging 2.36. Clumps containing as many as 22 stems have been reported in open subalpine stands of the Sierra Nevada (Tomback 1989).

Table 1—Stem number in *Pinus albicaulis* clumps appearing in 19 Montana-Wyoming stands. The stands are arranged in order of arboreal cover

Tree cover	Basal area	No. clumps per plot	Stand age	Single stemmed	Percentage of trees by stem number class										
					1	2	3	4	5	6	7	8	9	10	11
Percent	*m²/ha*		*Yr*	*Percent*											
21	5.1	43	40	21	21	23	26	12	7	5	2	4			
27	10.8	67	133	45	45	34	10	6	3	0	1	0	1		
33	12.7	50	116	48	48	28	12	10	0	2					
45	23.5	37	190	43	43	45	3	3	3	0	3				
48	13.5	32	210	65	65	13	13	3	6						
48	17.2	50	140	48	48	30	8	8	2	4					
50	11.5	26	290	92	92	8									
51	21.0	23	420	35	35	48	13	0	4						
55	15.3	34	160	59	59	29	9	3							
57	12.7	33	140	30	30	27	16	18	3	0	3	0	0	0	3
63	20.2	46	400	61	61	37	2								
66	13.4	72	113	53	53	21	14	7	3	1	0	1			
66	13.4	61	170	90	90	3	2	2	3						
67	15.3	68	113	56	56	21	12	7	1	3					
75	17.3	53	210	53	53	26	11	6	2	2					
78	17.8	54	225	61	61	23	9	7							
84	13.1	58	99	53	53	28	3	5	7	0	2	0	2		
84	17.3	43	289	60	60	28	6	4	0	2					
85	23.5	30	283	63	63	14	13	3	7						

CLUMP INITIATION

Many multistemmed whitebark pine clumps undoubtedly arise from different seeds deposited at one spot, most likely by nutcrackers (Hutchins and Lanner 1982), but occasionally by squirrels and chipmunks or, conceivably but rarely, by a cone falling intact (Linhart and Tomback 1985). One can easily demonstrate this by pulling clumps and counting entirely separate stems. We suggest that mature trees arising through this mechanism may be recognized by the acute angles between the stems of trees competing with each other; this form is illustrated by Linhart and Tomback (1985).

We give two lines of evidence that some whitebark pine clumps arise by spontaneous basal branching and note that damage to apical meristems by insects, vertebrates, or climate might also stimulate basal branching. First, of seedling clumps pulled in the field, some consist of single trees with a single root system. Second, nursery seedlings, planted one-seed-at-a-time, often have multiple stems. For example, seedlings grown from one lot of seeds were branched at the base in over 84 percent of the cases and exhibited stem frequencies even higher than those seen in natural stands of the region (tables 1 and 2). The developmental tendency of whitebark pine to branch at the base may be related to its tendency to branch profusely and widely at higher nodes—a tendency that has led dendrologists to contrast the "lyrately branching" form of whitebark pine with the conical form of most other Rocky Mountain conifers (Harlow and Harrar 1958). We suggest that obtuse basal branching, as well as strong crown branching, indicates a morphologic tendency of individuals that normally grow in open stands to optimize energetically through extensive branching. Such branching is energetically efficient because it develops a large canopy with minimal competition among branches and a minimal investment in trunk biomass. We suggest that—although forces such as crushing snow might sometimes spread clumps of genetically distinct individuals obtusely—obtuse basal branching often, or usually, indicates a genetically uniform clump.

Genotypic analysis of multistemmed clumps should shed light on the relative contributions of basal branching and the germination of clumped seeds to multiple stemming in particular whitebark pine stands. Analyses made in two Alberta stands (Furnier and others 1987) and one Wyoming stand (Linhart and Tomback 1985) show: (1) that while 58, 70, and 83 percent, respectively, of the clumps examined had mixed origins, as many as 42, 30, and 17 percent may have arisen by branching alone, and (2) that, while most clumps are of mixed origin, 22, 19, and 46 percent, respectively, of the stems in the mixed clumps were genetically undistinguished from their neighbors and may well have arisen by branching. Genotypic analysis may have misclassified some distinct stems as branches; this is unlikely in studies based on 11 loci (Furnier and others 1987), and somewhat more likely in studies based on only four loci (Linhart and Tomback 1985).

Table 2—Branching of pine seedlings grown under greenhouse conditions

Species	Sample size	Percent of seedlings with "X" branches				
		1	2	3	4	5
Pinus albicaulis	52	15	15	58	6	6
Pinus contorta[1]	198	90	10	0	0	0

[1]In contrast to *Pinus albicaulis* branches, the branches of *Pinus contorta* were weak and not competitive with the main stem.

SURVIVAL OF STEMS IN CLUMPS

We observed that while multiple-stemmed trees are common in open woodlands just below timberline, they are rare in denser forests a few tens of meters lower. We attribute the difference not to sources of multistems, but to the survival of clumped stems. In a closed forest, trees in a clump should be at a disadvantage. Trees in a clump are very dense, and the clump can be expected to self-thin if other trees are nearby. One might even expect all trees in the clump to disappear, since their competition with each other will reduce the likelihood that any one will grow fast enough to stay in the canopy. On the other hand, if the stand is open—due to its occupation of a marginal habitat where "safe sites" for establishment are few or if the stand is thinned—we expect the multistem habit to be most energetically efficient.

Multistems are most efficient in open stands because (1) single stems have less circumference than multiple stems of equal cross-sectional area, (2) leaf area is proportional to circumference (Marshall and Waring 1986; Shinozaki and others 1964), and therefore (3) branched crowns require less photosynthate per unit of leaf area for support than single stems do. For example, simple geometry shows that two-, three-, four-, and five-stemmed trees have 140, 172, 200, and 222 percent of the circumference (our leaf area index) of a single-stemmed tree with the same cross-sectional area (our index of photosynthetic cost). One wonders whether the basal area differences underestimate differences in structural costs, since clumped trees growing in open stands are generally shorter than relatives growing in closed stands. This seems unlikely since the shorter trees of clumps will have longer, more costly, radial reaches in both shoot and root zones; such compensation has been demonstrated in juniper (Weaver and Lund 1982). While hormonal coordination might allow single-genotype clumps to outperform multiple-genotype clumps or conjoined stems in a clump to outperform single-stemmed trees, we have no evidence for either hypothesis. Nor do we have estimates of the possible impacts of clumping on group function—whether they might be positive (by transpiration reduction through mutual shelter or water supply increases due to snowdrift creation) or negative (by evaporation of rain or snow from a large canopy).

If competition significantly affects the degree of multistemming in open versus closed stands of whitebark pine, we might expect the same phenomenon in stands of other tree species. With or without "cache-planting," one sees that clumping is most common in open stands. In contrast to its forest form, thick-barked Douglas-fir (*Pseudotsuga menziesii*) is often clumped at lower timberline and along rocky ridges at higher altitudes, probably as a result of damage to apical meristems and survival of multiple stems or perhaps nutcracker caching (Lanner 1988). Typically single-stemmed lodgepole becomes multistemmed at lower timberline in areas such as meadow borders in northwestern Yellowstone National Park, due to survival of multiple stems arising after leader damage or germination of seeds from a cone that fell intact. While subalpine fir (*Abies lasiocarpa*) is strongly single stemmed in forests, its lower branches root and layer to form tight clumps in mountain meadows (Billings 1969) and krummholz sites (Marr 1977). The tendency of pines in open stands of warmer environments such as *Pinus edulis* (Vanderwall and Balda 1977), and *Pinus ponderosa* and *Pinus flexilis* of Montana, to branch low and profusely, but without multistemming, may be an adaptation to decrease exposure to groundfire and/or high soil-surface temperatures.

CONCLUSIONS

From the above we conclude that:

1. Multiple stems could arise from basal branching, from multiple establishment of seeds deposited near each other, or both.
2. Either basal branching or seed caching could yield more stems per clump than normally occur in mature whitebark pine stands.
3. Whether it arises through basal branching or seed caching, stem number is ultimately controlled by competition among members of a clump (and declines therefore with clump age) and competition between adjacent clumps (and declines therefore with canopy closure).
4. Branching seems to account for 31, 26, and 46 percent of total multiple stemming in three particular whitebark pine stands. We speculate that branching may dominate in woodlands where most clumps are obtusely branched and may be less important in woodlands where most clumps are acutely branched.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from Dave Mattson)—Nutcracker-dispersed trees that were not multistemmed might support the branching hypothesis, what about *Pinus sibirica* and *Pinus pumila*?

A.—*Pinus edulis* and *Pinus flexilis*, from the lower timberline, are nutcracker-dispersed trees that are mostly single stemmed. It is not clear to me either why companion seedlings fail to establish or why the tree fails to branch lower; perhaps fire or high surface heat select against multiple stems. Clumping seems more characteristic of cooler-moister woodlands and may be due, as in *Pinus albicaulis*, to a combination of caching and basal branching. While multiple stems have been reported in *Pinus sibirica and Pinus pumila*, I do not know whether and under what conditions it is important; at this symposium Tomback and Holtmeier both described clumping in closely related *Pinus cembra*. Lanner (1988) described clumping in wing-seeded conifers (*Pinus longaeva* and possibly *Pseudotsuga menziesii*) dispersed by nutcrackers.

Q. (from Cathy Stewart)—Are the single stems typical of closed-canopy forests due to lack of caches or to competitive thinning?

A.—I see both single-stem and multiple-stem reproduction in relatively dense stands. I would therefore attribute the lack of mature multiple-stem clumps to thinning induced by within-clump and between-clump competition.

Q. (from Ron Lanner)—If branching occurs at both the base and the crown of whitebark pine trees, why is it rare on the lower trunk?

A.—Our seedlings branched naturally and it is obvious that upper crowns branch naturally. I agree that branches on the lower trunk are rare, but have no solid explanation for their absence there; browsing or sand and snow blowing near the ground surface may contribute.

XYLEM RESIN MONOTERPENES OF WHITEBARK PINE IN THE SIERRA NEVADA AND SOUTHERN CASCADES

R. H. Smith

ABSTRACT

A preliminary study was made of the xylem monoterpenes of whitebark pine in the southwestern portion of its range to determine local and regional variation in components and composition. Three stands were sampled: Mount Rose, Nevada—43 trees; Mount Shasta, California—62 trees; Paulina Mountains, Oregon—23 trees.

The mean, maximum, and minimum of β-pinene, 3-carene, myrcene, and limonene varied greatly between stands. The greatest differences were between the Mount Rose stand and the two Cascade stands. 3-carene was usually the highest percentage in individual trees; but myrcene was highest in some trees. Other components occurring in small amounts were α-pinene, camphene, β-phellandrene, and terpinoline.

The overall frequency distribution of each of the four variable components suggested high, medium, and low classes to characterize the amounts in individual trees and to express total tree composition with four digits. When so classified, about 95 percent of the trees at Mount Rose differed from trees at Mount Shasta. The compositional types at Mount Shasta and in the Paulina Mountains were somewhat similar, but they differed markedly in frequency.

Thus, it is concluded that there is appreciable difference among the three stands in the frequency of genes or alleles for the expression of xylem resin monoterpenes.

INTRODUCTION

Five pine species are placed under the subsection *Cembrae*: one in North America, *Pinus albicaulis* Engelm. (whitebark pine), and four in Eurasia, *P. sibirica* DuTor., *P. cembra* L., *P. pumila* Regel., and *P. koraiensis* Sieb. and Zucc. Mirov (1961) reported that the xylem monoterpene of whitebark pine is almost completely 3-carene while that of the four Eurasian species consists of α-pinene and β-pinene with smaller amounts of 3-carene and limonene. Local and regional variation was not reported by Mirov because the sampling and analytical procedures of that time were long and cumbersome, and to explore local and regional variation would have been a substantial undertaking. It was also difficult with those older procedures to determine the presence of small amounts of components. Though early studies were thus limited, they did provide an excellent basis for further research.

More recently, through the use of improved techniques for examining large numbers of small samples, considerable local or regional variation in xylem monoterpene composition has been found in many pines of western North America: *P. muricata* D. Don (Forde 1964), *P. torreyana* Parry (Zavarin and others 1967), *P. radiata* D. Don (Williams and McDonald 1962), *P. aristata* Engelm. (Zavarin and others 1976), *P. coulteri* D. Don, *P. washoensis* Mason and Stockwell, *P. ponderosa* Laws., *P. contorta* Dougl., (Smith 1967, 1977, 1983), and *P. monophylla* Torrey and Frem. (Smith and Preisler 1988). In a preliminary study considerable variation was found in the young progeny of six pine species of Mexico (Smith 1982).

I know of no report on the intraspecific variation of the xylem monoterpenes of whitebark pine. This paper reports a preliminary study of the local and regional variation of the xylem monoterpenes of whitebark pine in the southwestern portion of its range. Such information could be of value in refining the description of the species and in research on its specificity to bark beetle attack.

METHODS AND MATERIALS

Three stands of whitebark pine were sampled for xylem resin (fig. 1, table 1). This portion of the tree's range is characterized by small, widely separated stands at high elevation. Diameter of the trees sampled ranged from 10 cm to 45 cm; most were 15 cm to 20 cm. All trees were probably greater than 40 years old. Each tree was tapped at a height of 1.5 m with a 1.4-cm bit. The tap hole was at a slight upward angle, and went through the bark and phloem and for about 8 mm into the xylem. A 5-cc shell vial was fitted into the tap hole to collect the resin. Two to three days later the vials were removed and corked.

An aliquot of 0.1 to 0.5 cc of the sample of resin and an approximate equal amount of chromatographic grade pentane were combined in a 1-cc screw cap vial. These prepared samples were refrigerated at 0 °C except when being processed.

The prepared samples were analyzed for monoterpene content by gas liquid chromatography (Smith 1977), using a thermal conductivity detector, a β, β' oxydipropionitrile column, and a sample size of about 1.0 µl. The results of the analysis were recorded by a reporting integrator and were expressed as normalized composition—each component was calculated as a percentage of the total monoterpene in the sample. Peaks were identified by a combination of relative retention time, introduction of internal

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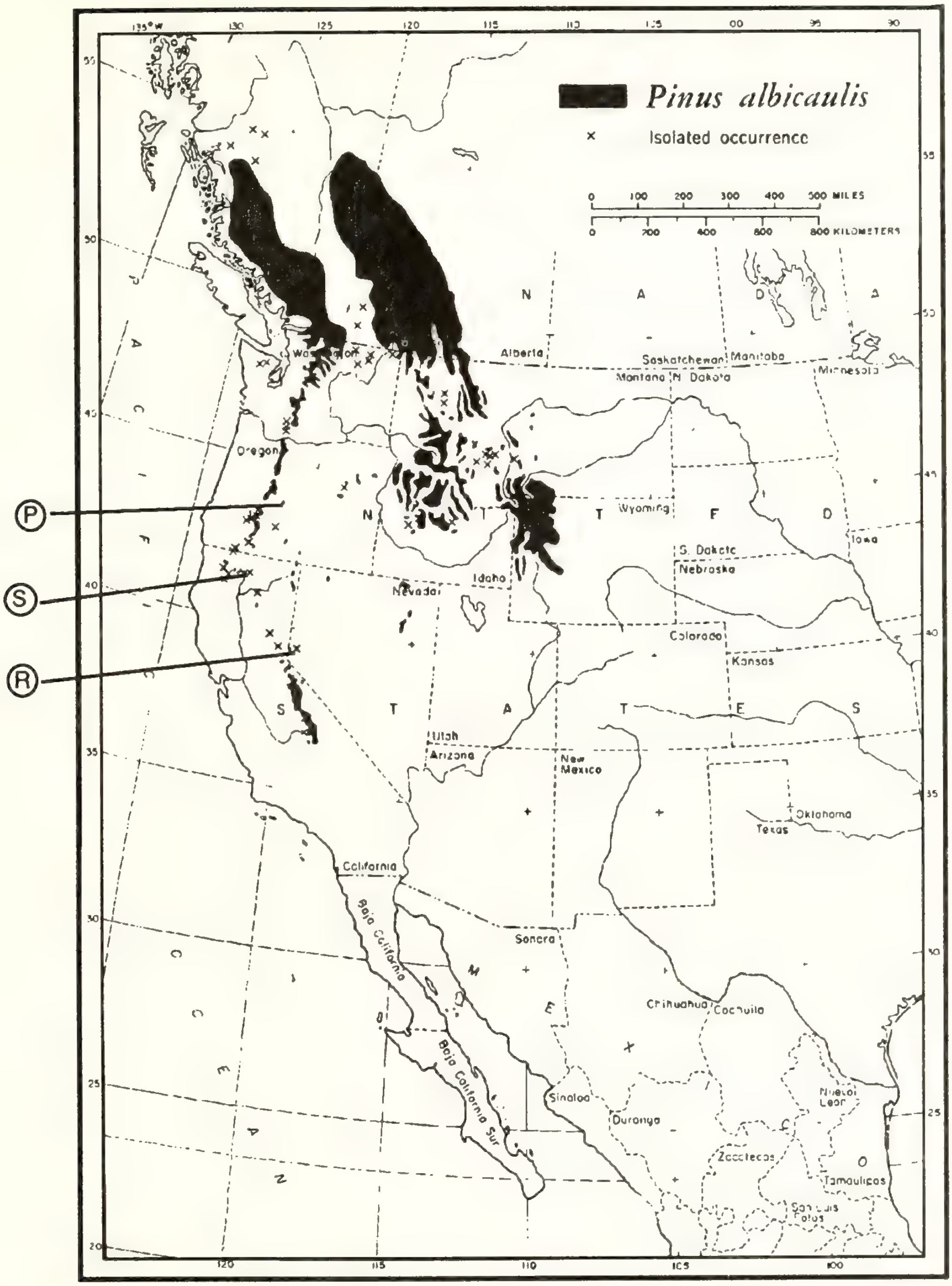

Figure 1—Location of three stands of whitebark pine sampled for xylem resin monoterpenes, P = Paulina Mountains, S = Mount Shasta, R = Mount Rose. Distribution taken from Critchfield and Little (1966).

Table 1—Number of trees sampled and sampling dates for three study locations

Number of trees sampled	Locale	National Forest	Mountain range	Date sampled
43	Mount Rose	Toiyabe	Sierra Nevada	September 1986
62	Mount Shasta	Shasta-Trinity	Cascades	August 1987
23	Paulina Mountains	Deschutes	Cascades	June 1988

standards, and from the experience of analyzing large numbers of resin samples.

Average composition and the maximum and minimum for each component were calculated for each stand. The frequency distribution of each variable component was plotted. The modes of each of the multimodal distributions were estimated, and their limits were defined when the distribution of a component for all three stands was viewed as a whole. Since there were, generally, three modes in the distribution of four of the components, numerical values of 0, 1, and 2 were given to the low, medium, and high modes, respectively. The percentage composition of each tree was converted to a four-digit value, one digit for each of the four variable components, by applying the 0, 1, 2 definition. The normalized distribution of the kinds of composition was then calculated for each stand, and the three stands were compared on the basis of the frequency of types of composition.

RESULTS AND DISCUSSION

The three whitebark pine stands differed considerably in average composition of xylem monoterpenes and in the range of the components (table 2). However, no composition of any tree in the three stands resembled that which Mirov (1961) reported for the other four species of *Cembrae*. The two Cascade plots differed much more from the Sierra Nevada plot than they differed from each other. However, there were noticeable differences between the two Cascade plots. Although in a normalized analysis a change in one component can cause a change in another, the total monoterpene content of whole resin was fairly constant. Thus, the normalized system is a close approximation of the absolute amounts, and the differences observed can be considered real.

As Mirov (1961) had reported, 3-carene was the principal component of the xylem monoterpenes of whitebark pine at Mount Rose, but small amounts of α-pinene, myrcene, limonene, and terpinoline along with trace amounts of ß-pinene and ß-phellandrene were also found in nearly all trees in this study. As with other pines, there is a strong, positive association of 3-carene and terpinoline. However, the ratio of the two components was quite different; in whitebark the ratio of 3-carene to terpinoline was about 10 to 1, whereas in most other pines it is about 20 to 1.

Though 3-carene was also the principal component in the two Cascade stands, there were considerable and variable amounts of myrcene, ß-pinene, and to a limited extent limonene in most trees (table 2). The ratio of 3-carene to terpinoline was, as in the Mount Rose trees, about 10 to 1, and there was a small amount of α-pinene, in all trees and a trace amount of ß-phellandrene in most trees. Although the averages of several components were about the same in the two Cascade stands, the maximum and minimum were usually different. This could have been caused by differences between the two stands in the size of the sample. That is, in a species so variable, it may be necessary to have a large sample size—from my experience 70 to 100 trees—to consistently estimate the range of variation. The two Cascade plots differed markedly in the mean and range of ß-pinene and 3-carene (table 2). The difference between the two plots in sabinene is caused by one tree at Paulina with 23 percent sabinene. As in several other pines, there was a strong positive relationship between sabinene and terpinoline, with nearly a one-to-one ratio. Therefore, the tree with a large amount of sabinene also had a large amount of terpinoline.

Table 2—Xylem resin monoterpenes of *Pinus albicaulis* in three stands: Mount Rose, Mount Shasta, Paulina Mountains; $\bar{X}$ = mean, SD = standard deviation

	Mount Rose $n = 43$			Mount Shasta $n = 62$			Paulina Mountains $n = 23$		
Component	$\bar{X}$	SD	Max/Min	$\bar{X}$	SD	Max/Min	$\bar{X}$	SD	Max/Min
	Percent[1]		*Percent*	*Percent*[1]		*Percent*	*Percent*[1]		*Percent*
α-pinene	1.9	0.59	4/1	2.7	1.24	8/2	2.9	1.14	5/0
ß-pinene	.3	.16	1/*	4.6	7.35	39/*	11.4	6.87	20/0
3-carene	83.2	5.35	94/70	54.0	9.37	82/40	45.1	13.70	68/8
sabinene[2]	.0	—	—	.0	—	—	1.0	4.69	23/0
myrcene	6.1	4.79	18/*	28.1	10.46	44/1	27.8	11.43	69/16
limonene	1.0	1.11	5/0	3.6	3.35	11/0	3.4	3.52	14/0
ß-phellandrene	.4	.25	1/0	.3	.44	1/0	1.3	3.18	16/0
γ-terpinene	*	—	—	*	—	—	*	—	—
terpinoline	6.9	2.42	14/0	6.0	1.21	11/4	6.8	3.45	20/2

[1] = normalized.
[2] = all in one tree at Paulina.
* = trace, less than 0.1.

Three trees at Paulina are of note, the one high in sabinene discussed above, one high in myrcene, and one high in ß-phellandrene. The normalized percent composition of these three trees was:

	Percent composition		
Component	**Tree 1**	**Tree 2**	**Tree 3**
α-pinene	2.6	3.6	4.9
ß-pinene	11.3	trace	21.1
3-carene	8.1	23.9	21.2
sabinene	23.0	0.6	trace
myrcene	25.3	68.8	26.0
limonene	8.9	trace	6.8
ß-phellandrene	trace	trace	16.1
terpinoline	20.0	4.0	4.1

Are these three trees unusual, or are there other similar trees in other parts of the species distribution?

The three stands differ markedly in the frequency distribution of four variable components: ß-pinene, 3-carene, myrcene, and limonene (fig. 2). All four frequency distributions have a tendency to be tri-modal, when all three stands are viewed together. The best approximation of the three modes and the intervals that describe them is given in table 3. The similarity and differences between the two Cascade plots are clearly evident from the frequency distributions (fig. 2).

The types of monoterpene composition in each stand—obtained by converting the composition of each tree to a four-digit value using table 3 and then normalizing the types of composition for each of the three stands—shows

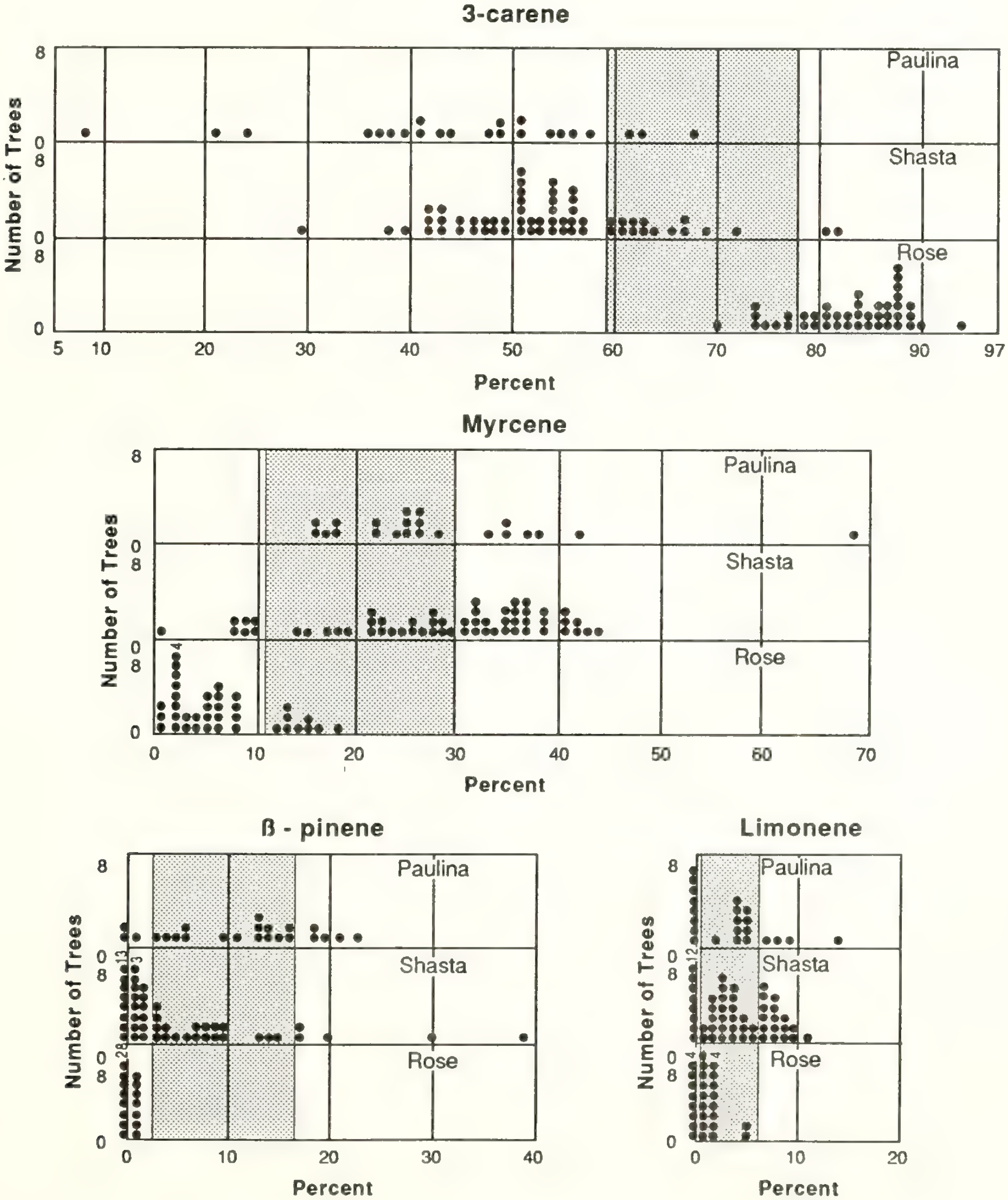

Figure 2—Frequency distribution of 3-carene, myrcene, ß-pinene, and limonene in three stands of whitebark pine: Paulina Mountains, Mount Shasta, Mount Rose. Numbers at top of a line of plotted points are the additional number of points for that percentage. The medium mode is shaded for the distribution of each component.

that each stand is sharply different from each other (tables 4 and 5). Again, the large difference between the Sierra Nevada plot and the two Cascade plots is clearly evident (fig. 2 and tables 4 and 5), and the substantial difference between the two Cascade plots is also clearly evident. That is, the types of composition found in the two Cascade plots are somewhat similar, but their frequencies are quite different.

The coefficient of determination between the stands was very low (about 0.1), though one might question the use of this analysis because of the large differences in the numbers of trees in the three stands. Even without the coefficient of determination, the differences between stands is clearly evident. The two Cascade plots are clearly different in the frequency of types, and the Sierra Nevada stand is clearly different from the two Cascade plots in both the kinds of and frequencies of compositional types. Likewise, the numbers of compositional types in the three stands are very different, with only four types at Mount Rose, 13 types at Paulina, and 21 types at Mount Shasta.

These differences in means, ranges, and in the kinds and frequency of compositional types suggest that there are major genetic differences between the Cascade and Sierra Nevada stands and minor genetic differences between the two Cascade stands. It should be reemphasized

Table 3—Intervals for low-, medium-, and high-frequency modes of the four variable components of whitebark pine xylem monoterpenes, ß-pinene, 3-carene, myrcene, limonene

Mode	Code value	Component ß-pinene	3-carene	myrcene	limonene
		Percent			
Low	0	0-3	0-58	0-10	0
Medium	1	4-16	59-78	11-30	1-6
High	2	17-100	79-100	31-100	7-100

Table 4—Coded types of xylem monoterpene composition of whitebark pine and the average actual composition of these coded types for 128 trees

Coded type[1]	N	Actual composition[2] α-p	cam	ß-p	car	sab	myr	lim	ß-ph	γ-t	ter
		Percent[3]									
0011	1	2.5	—	2.2	56.0	—	29.2	3.7	0.3	0.4	5.4
0012	4	1.7	*	.3	54.2	—	28.3	9.4	*	.5	5.6
0020	11	2.5	0.1	.7	49.3	0.1	41.2	*	.5	.1	5.5
0021	14	2.4	*	1.5	51.8	*	34.7	3.4	.3	.1	6.4
0022	4	2.3	*	.6	42.3	—	41.8	7.0	.3	.1	5.6
0110	9	1.8	.1	.4	74.3	—	13.8	.2	.5	—	8.9
0120	1	1.9	.3	.8	60.0	—	31.3	.5	.3	—	4.7
0111	3	1.7	*	.5	63.4	—	23.0	3.5	.2	.2	7.5
0112	5	1.6	.1	.2	61.9	—	21.5	8.6	*	.2	5.7
0200	6	2.4	.3	.4	84.7	—	4.6	.2	.3	.1	6.8
0201	29	1.9	*	.3	85.1	—	4.0	1.4	.3	*	7.0
0210	2	1.5	*	.3	79.5	—	12.6	.3	.2	—	5.5
1010	3	3.2	*	12.3	53.8	*	23.6	*	.3	—	6.7
1011	4	2.8	.1	10.8	49.7	*	23.0	4.9	1.0	*	7.6
[4]1012	6	2.6	*	11.2	43.2	3.8	21.0	9.9	.3	—	8.4
1020	7	4.3	*	10.1	44.4	*	35.6	*	.3	—	5.1
1021	1	2.5	*	5.4	41.1	*	41.9	4.5	.6	—	3.9
1110	2	1.8	*	9.5	63.1	*	17.6	*	.4	—	7.7
1101	3	2.5	*	8.1	67.2	—	9.6	4.8	.7	—	6.7
1111	2	2.1	.1	5.0	64.5	*	16.4	3.4	.4	—	7.8
1112	1	2.7	*	6.6	60.7	—	16.7	6.7	.3	—	6.5
2001	2	5.8	.2	34.4	48.0	—	4.5	2.1	.2	—	4.8
2010	3	4.2	*	19.3	47.0	*	22.2	*	.4	—	6.1
2011	4	4.3	.2	18.8	42.3	*	25.7	2.9	.6	—	5.0
2012	1	4.9	*	21.1	26.2	*	26.0	6.8	16.1	—	4.1

[1]From left to right: ß-pinene, 3-carene, myrcene, limonene; see table 3 for values of code numbers.
[2]From left to right: α-pinene, camphene, ß-pinene, 3-carene, sabinene, myrcene, limonene, ß-phellandrene, γ-terpinene, terpinoline.
[3]Average for the normalized composition for the trees in each type.
[4]One tree with 23 percent sabinene and 20 percent terpinoline.

Table 5—Frequency distribution of coded types of xylem monoterpene composition in three stands of whitebark pine; see table 4 for actual composition of coded types

Coded type	Stand		
	Paulina Mountains	Mount Shasta	Mount Rose
	Percent[1]		
[2]0011	—	1.6	—
0012	—	6.5	—
0020	4.3	16.1	—
0021	8.7	19.4	—
0022	—	6.5	—
0110	—	1.6	18.6
0120	—	1.6	—
0111	4.3	3.2	—
0112	—	8.1	—
0200	—	3.2	9.3
0201	—	—	67.4
0210	—	—	4.7
1010	8.7	1.6	—
1011	13.0	1.6	—
1012	[3]13.0	4.8	—
1020	13.0	6.5	—
1021	4.3	—	—
1110	4.3	1.6	—
1101	—	4.8	—
1111	4.3	1.6	—
1112	—	1.6	—
2001	—	3.2	—
2010	8.7	1.6	—
2011	8.7	3.2	—
2012	[4]4.3	—	—

[1]Normalized for each stand.
[2]From left to right: α-pinene, 3-carene, myrcene, limonene.
[3]One tree with 23 percent sabinene and 20 percent terpinoline.
[4]Tree also has 16 percent β-phellandrene.

that the study was limited to a small portion of tree range. And it is apparent that with such large local variation, larger numbers of trees are needed at both the Mount Rose and Paulina Peak stands to improve the analyses. Obviously, too, a survey of the rest of the species distribution would be useful.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from Ron Lanner)—How does *Pinus albicaulis* compare to *P. flexilis* in monoterpenes?

A.—Within the limits of my data, the two species are distinctly different. None of the 128 *P. albicaulis* examined had more than 8 percent α-pinene, with an average of about 2.5 percent. Of the 10 trees of *P. flexilis* examined, none had less than 28 percent α-pinene, with an average of about 55 percent. *Pinus albicaulis* can be separated from *P. monticola* on the same basis.

FIRE EFFECTS IN WHITEBARK PINE FORESTS

Penny Morgan
Stephen C. Bunting

ABSTRACT

Although whitebark pine (Pinus albicaulis) *forests frequently burn, little is known about the patterns of regeneration, growth rates, and successional development of these forests as they are influenced by fire frequency. This paper presents such data collected from seral whitebark pine stands in the Shoshone National Forest, WY.*

Cross-sections were collected from fire-scarred whitebark pines. Fires have occurred often in the past, and the larger trees often survive low-intensity fires. Many trees have been scarred by more than one fire. Young whitebark pine trees populate recent burns. Relative ages and growth rates of whitebark pine and associated conifers have been determined. On sites where it is seral, whitebark pine is gradually replaced by subalpine fir (Abies lasiocarpa) *and Engelmann spruce* (Picea engelmannii) *in the absence of fire. Frequent fires prevent or slow the replacement of whitebark pine by these more shade-tolerant and less fire-resistant conifers.*

Based on a composite of samples and a synthesis of the literature, successional patterns in seral whitebark pine forests are documented. Fires rejuvenate and maintain the productivity of seral whitebark pine stands. Fires are thus important to regeneration and long-term maintenance of seral whitebark pine forests.

INTRODUCTION

Whitebark pine (*Pinus albicaulis*) is an important species in subalpine ecosystems throughout the Northern Rocky Mountains. It is an early successional species in many habitat types (Pfister and others 1977; Steele and others 1981, 1983) and may occur in both pure and mixed stands.

In substantial areas of the species' natural distribution, whitebark pine populations are declining in abundance (Arno 1986). White pine blister rust (*Cronartium ribicola*) has reduced many stands in the Northern Rocky Mountains. Mountain pine beetle (*Dendroctonus ponderosae*) has also affected populations in some areas. Seral whitebark pine stands are being replaced by more shade-tolerant species, particularly subalpine fir (*Abies lasiocarpa*).

Fire may play an important ecological role in seral whitebark pine stands. Whitebark pine regeneration is favored in the open conditions created by fires or other large-scale disturbances, but little is known about the role of fire in the maintenance and management of whitebark pine. We studied successional patterns relative to fire history in two habitat types. Specific objectives were to:

1. Collect and interpret detailed fire history data.
2. Identify past regeneration patterns for whitebark pine and determine their relationship to fire history.
3. Analyze stand age and size structure of whitebark pine and associated conifer species in stands where whitebark pine is seral.

LITERATURE REVIEW

Whitebark pine is a subalpine white pine of the Northern Rocky, Sierra Nevada, and Cascade Mountains. Loope and Gruell (1973) found whitebark pine from 2,400 and 3,050 m, often in nearly pure stands just below timberline. It is most common on thin soils of igneous origin (Harlow and Harrar 1969), but may occupy other soils (Weaver and Dale 1974). It may be small, scrubby, and multistemmed (krummholz) near timberline or can attain commercial size and good form in mixed stands at lower elevations.

The stands are open, with large whitebark pines often occurring in clumps (Weaver and Dale 1974). Stands may be even or multiaged. Whitebark pine occurred in 36 of 50 habitat types identified in eastern Idaho and western Wyoming by Steele and others (1983). Whitebark pine may occur as a seral stage dominant or in pure or mixed climax stands.

Whitebark pine is an important source of food for wildlife in the Greater Yellowstone Ecosystem. Red squirrels, grizzly bears, and Clark's nutcrackers are particularly dependent on the large, high-protein seeds produced by whitebark pine, but numerous other birds and rodents also eat the seeds (Craighead and others 1982; Eggers 1986; Hutchins and Lanner 1982; Tomback 1982).

Arno (1986) calculated a mean fire-free interval of 30 to 41 years with a range from 4 to 78 years for fires occurring in large stands (100 to 300 ha) in upper subalpine habitat types where whitebark pine is a seral species and replaced at climax by subalpine fir. For small areas less than 1 ha, Arno and Petersen (1983) found mean fire-free intervals to vary between 72 and 94 years. Romme (1982) estimated a fire-free interval of about 300 years for much of the lodgepole pine forest of Yellowstone National Park, and this interval may reflect conditions of the adjacent whitebark pine forests as well.

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Whitebark pine is a pioneer on burns (Weaver and Dale 1974) and may dominate for 225 years or more (Loope and Gruell 1973). Whitebark pine trees grow slowly in both diameter and height (Weaver and Dale 1974). Although whitebark pine has thin bark, it often occurs on dry sites in open stands, which reduces fire intensity and, consequently, the tree's vulnerability to fire (Fischer and Clayton 1983). The common associates of whitebark pine are, in order of increasing fire resistance: subalpine fir, Engelmann spruce (*Picea engelmannii*), and lodgepole pine (*Pinus contorta*). Douglas-fir (*Pseudotsuga menziesii*) and aspen (*Populus tremuloides*) are relatively fire resistant and are occasionally associated with whitebark pine at its lower elevational limit. The most common associates in the Yellowstone region are subalpine fir and lodgepole pine.

METHODS

The Russell Peak study area is located approximately 25 km northwest of Cody, WY, in the Crandall Ranger District, Shoshone National Forest. The study area is about 750 ha in area with elevations from 2,300 to 2,800 m. Soils are immature and primarily formed from andesite and volcanic breccia of the Wapiti Formation (Pierce and Nelson 1971).

The majority of the seral whitebark pine stands in the study area occur on *Abies lasiocarpa / Vaccinium scoparium or Abies lasiocarpa / Arnica cordifolia* habitat types (Steele and others 1983). To determine the response of the species through time, sample stands were selected to represent a variety of successional stages on these two habitat types.

Eight mid-seral and two late-seral stands were sampled. Macroplots were 50 by 50 m (0.25 ha) in size. All trees greater than 1.4 m in height of all species were aged by taking an increment core at breast height. A subsample of trees was cored at both the base and 1.4 m to determine an adjustment, by species, for total age. Basal diameter of all saplings, those individuals less than 1.5 m and greater than 0.5 m in height, was recorded on the macroplot. A subsample of saplings was cored at the base or cross-sectioned to determine an age-height relationship. Density of seedlings, those individuals from 0 to 0.5 m in height, was estimated within five 2- by 20-m belt transects. Obtaining the total age of all trees on the plot allowed analysis of stand dynamics.

At three locations within a 100-ha sample area, cross-sections were collected from trees with multiple fire scars. All three locations had a minimum of three trees with multiple fire scars and were located near sample plots. Cross-sections were sent to the Laboratory of Tree-Ring Research at the University of Arizona for analysis. Cross-sections were sanded and cross-dated using the skeleton plot technique (Stokes and Smiley 1968; Swetnam and others 1985). Based on characteristic cell structure, scars were classified as having high or medium probability of resulting from fires, or as scars probably created by other means, such a windthrow or black and grizzly bear feeding. Skeleton plots were made for each cross-section, and in some cases for two or more radii per tree. The skeleton plots were compared among the whitebark pine cross-sections and to two different tree-ring chronologies from the Yellowstone region, a Douglas-fir and limber pine series from Gardiner, MT (Drew 1975). Unfortunately these chronologies did not cross-date satisfactorily with the whitebark pine specimens. However, cross-dating was observed on the skeleton plots among the whitebark pine cross-sections.

Fire scars were dated by their position within dated annual rings (Arno and Sneck 1977; Dieterich and Swetnam 1984). Relative positions of scars within annual rings were also noted where possible, so that inferences regarding seasonal timing of past fires might be made (Barrett 1981; Dieterich and Swetnam 1984). Many scars of varying severity were found on the cross-sections. Only those scars that had a high probability of being caused by fire were used to estimate the fire-free intervals (FFI). These scars were selected through inspection of the tree, the morphology and shape of the scar, and subsequently developed woody tissue.

RESULTS

Data from the 10 stands sampled near Russell Peak indicate a variety of tree compositions. The combined data for all stands show that most of the whitebark pine in the area regenerated 100 to 300 years ago (fig. 1) and is presently declining in abundance (fig. 2). General successional patterns and fire history data for stands on the two habitat types are similar and are presented together here. Subalpine fir, which established in the past 200 years, is beginning to dominate many sites. Lodgepole pine and Engelmann spruce are present in small amounts only and do not comprise a significant amount of any stand.

Scars from 14 trees found within a 100-ha area in the general area of Russell Peak were dated. The FFI prior to 1875 was estimated to be 29 years, based on an average of all intervals between fires on individual cross-sections. The average FFI for the three groups of cross-sections varied from 13 to 46 years. Fire was relatively common within the Russell Peak area prior to 1850. The last fire that can be documented occurred in 1867.

The fire scar data indicate that in the Russell Peak region fires were much more common from 1700 to 1850 than they have been since 1850. More than 40 probable fire scars formed during this period in the 14 whitebark pine sampled. Most of the fires were small, as they scarred only one tree. There were, however, some years in which more than one tree was scarred in two or more of the three fire-history data locations. When two or more scars were dated to the same year, it was assumed that the fire affected a larger area than when only one tree was fire scarred. Our data indicate that such large fires occurred in 1595, 1672, 1693, 1721, 1810, 1825, 1836, 1848, and 1858. The average interval between these fires is 33 years with a range of 10 to 77 years. No such large-scale fire can be documented after 1858.

Even the more conservative 33-year FFI in the Russell Peak region is extremely short for whitebark pine survival. Whitebark pine grows slowly and may not achieve reproductive maturity until at least age 50 (Morgan and

Bunting 1989); most trees do not produce large numbers of seeds until at least age 70. Even if many mature whitebark pine trees survived the fires, it is doubtful that the species could persist with fires occurring so frequently. We are limited by having few trees dating prior to 1750, but it appears that fires were more frequent in the Russell Peak area between 1780 and 1850 than prior to 1780. The reasons for this are not evident but may be related to American Indian movements, climatic changes, or random variation in natural ignition. The frequent fire occurrence between 1780 and 1850 significantly lowers the average FFI and may not reflect the long-term conditions under which the species existed in prehistoric periods.

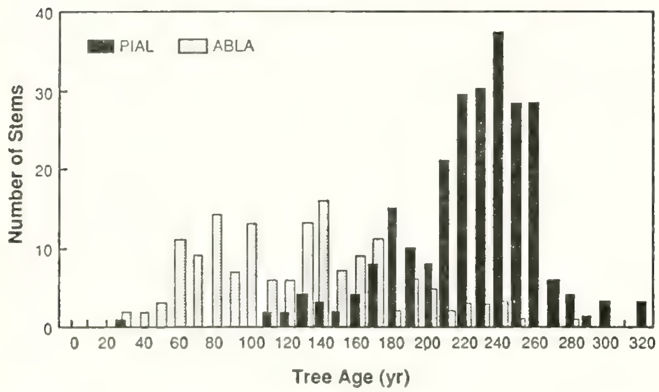

Figure 1—Combined distribution of whitebark pine (PIAL) and subalpine fir (ABLA) trees by 10-year age classes for 10 stands on the Shoshone National Forest, WY.

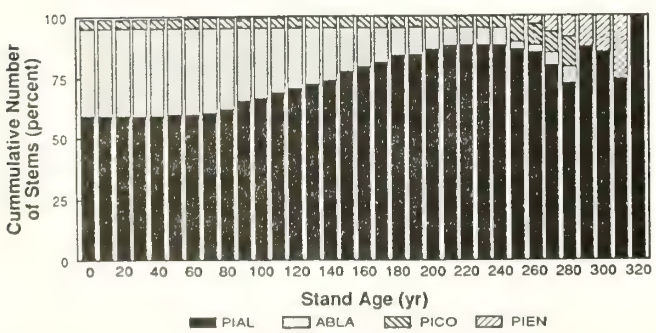

Figure 2—Percentage of the 10 sampled stands in the Shoshone National Forest, WY, comprised of the major conifer species, whitebark pine (PIAL), subalpine fir (ABLA), lodgepole pine (PICO), and Engelmann spruce (PIEN) through time.

No scars of any origin were found in the Russell Peak area dating after 1894. These data suggest that sources of scars, which include fires and grizzly bears, have been reduced since the late 1800's. At that time, an expanding range livestock industry in western Wyoming may have resulted in both killing of grizzly bears as predators and less frequent fires due to removal of the fine fuels by grazing. The American Indian was also displaced during this period. The other possibility is that the region has undergone a slight climatic change that has made fires less likely to occur.

The reduced fire frequency in the last 130 years has allowed subalpine fir to regenerate in abundance (figs. 1 and 2). Fewer fires have probably limited the opportunity for successful regeneration of whitebark pine. Fires create more open stands and expose mineral soil, which are necessary for establishment of whitebark pine seedlings. Whitebark pine can regenerate in duff or under a closed overstory but seldom succeeds in becoming a mature individual under these conditions.

Fires apparently occurred during different seasons of the year (table 1). Fires were relatively evenly distributed throughout the growing season for whitebark pine. Large fires, those that scarred more than one tree, occurred more frequently late in the growing season or when whitebark pine was dormant. Thus, most fires that occur are small, burning only one or a few trees, and they occur at any time during the growing season. Occasionally, such as in 1805, 1810, 1819, 1828, and 1858, large-scale fires apparently occurred in mid- to late summer or early fall.

The majority of the stands had significant amounts of subalpine fir regeneration. Stand 5 is typical (fig. 3). This stand was classified as an *Abies lasiocarpa/Arnica cordifolia* h.t. Most of the whitebark pine trees are over 200 years old and predate a series of fires that burned in the stand in the late 18th and early 19th centuries. The lodgepole pine present in the stand also predates these fires. Most subalpine fir has become established since the last fire, which occurred in 1867. No fires can be documented in the stand after 1867. There is a gap in conifer regeneration between 160 and 200 years ago. This gap coincides with a period when fires were very frequent in the stand, occurring in 1789, 1794, 1798, 1805, and 1810. The short FFI during this period probably prevented all conifer regeneration on the site. The period between 1829 and 1845 also had short FFI with the occurrence of four to five fires during this time. The canopy is now closed and few conifers have established in the last 50 years (an established conifer is defined as one greater than 1.5 m tall).

Our data show that whitebark pine frequently survives fires, since we found fire-scarred trees in virtually every stand we sampled. We hypothesize that the stands are likely to burn only when they are very young, when there is sufficient fine fuel in the form of herbaceous understory vegetation, or late in the successional development, when there is sufficient regeneration of subalpine fir and an accumulation of downed and dead woody fuel in the stand. Topography and structure of the adjacent stands may also be important based on limited field observations of areas that did and did not burn in the Yellowstone area fires of 1988.

Table 1—Distribution of fire occurrence by season in the Russell Peak area, Shoshone National Forest, WY, as determined by the method of Dieterich and Swetnam (1984) where the position of the scar within the growth ring is noted

Probability that fire caused scars	Season of fire[1]			Number of fires
	Early	Late	Dormant	
	Percent			
Highly probable	48	19	33	33
Probable	38	22	40	58

[1]Relative to growing season for whitebark pine.

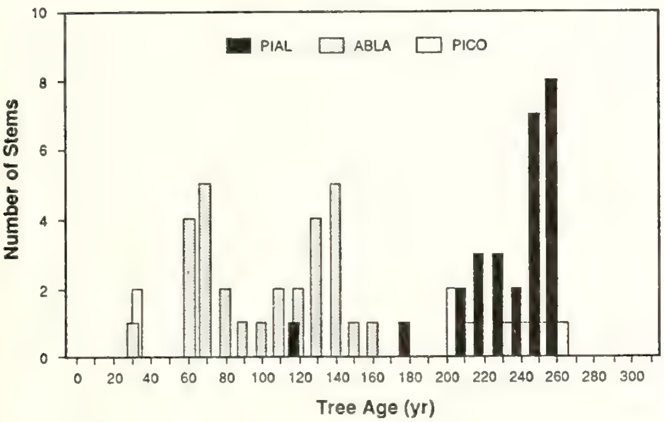

Figure 3—Distribution of whitebark pine (PIAL), subalpine fir (ABLA), and lodgepole pine (PICO) by age in stand number 5 in the Russell Peak area, Shoshone National Forest, WY.

SUMMARY AND CONCLUSIONS

Our data indicate that fire was much more common in the Russell Peak area of the Shoshone National Forest 150 to 300 years ago and had an average FFI of less than 50 years. Few fires have occurred there since 1850, and there is no evidence of any since 1900. Whitebark pine is seral to subalpine fir on most of the area, and the absence of fire has resulted in an increase in the abundance of subalpine fir. Few whitebark pine trees greater than 1.5 m in height were observed in the closed-canopy stands. If the current trend in regeneration continues, whitebark pine will continue to decline in abundance.

Fire may be very important in maintaining healthy, productive populations of whitebark pine in the face of competition from less fire-resistant tree species. In the absence of fire, cone production of whitebark pine may decrease as more shade-tolerant and less fire-resistant trees increase in abundance, thereby competing with or replacing whitebark pine. If this trend continues throughout the Yellowstone region, there will be fewer whitebark pine seeds available for wildlife or for regeneration of new whitebark pine stands.

The likelihood of fire occurrence changes with the development of the forest stand. The probability of fire spread is initially high following high-intensity fires due to the increase in the herbaceous component of the plant community. Although whitebark pine regenerates readily following high-intensity, stand-replacing fires, the trees are not likely to survive subsequent fires that occur while they are still small and easily killed. As the stand develops, the likelihood of fire is reduced because the fine fuels are suppressed by the conifer overstory. During this period the probability of a high-intensity, stand-replacing fire is low. However, low-intensity surface fires may occur. Fire likelihood and severity increase as subalpine fir becomes established in the stand, creating a fire ladder. Thus the more advanced successional stages become susceptible to stand-replacing fires.

ACKNOWLEDGMENTS

We are indebted to the many people who contributed to this research project. In particular we would like to thank Steve and Nathan Arno, who helped collect the fire history cross-sections, and Tom Swetnam, who supervised the tree-ring analysis. Personnel of the Bridger-Teton and Shoshone National Forests and Yellowstone National Park also assisted us.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from T. W. Weaver)—You gave data from two stands (one with spruce-fir regeneration and one without). Please argue for and against their occupying the same habitat type.

A.—Argument against being same habitat type:
The existence of a stand for 150 years without the development of a subalpine fir codominant or subdominant layer in the absence of fire or other disturbance is good evidence that the site is not suitable for subalpine fir and is, therefore, probably not an *Abies* habitat type.

Argument for being the same habitat type:
There were a number of mature subalpine fir within the general area, and three within the boundary of the stand. In addition, there were a large number of small subalpine fir (less than 1.5 m in height) distributed throughout the stand, which indicates that the species could exist on the site, although it may require a long time for the species to dominate.

Q. (from Roger Andrascile)—Why couldn't you use recently fallen trees to get fire history rather than damage standing live trees—why use the chainsaw technique?

A.—Dead trees cannot be used unless they can be crossdated with other trees in the sample or with an existing tree-ring chronology to obtain accurate dates. We did use some dead trees in the study. The increment core technique of Barrett and Arno (1988) is a nondestructive method to determine fire history but is not as accurate for determining the occurrence of buried scars or scars that are only a few years apart. For most of our research on whitebark pine (manuscript in preparation) this method was used, but we wanted to check the increment core technique against a more accurate standard. It is also possible to take partial sections from standing live trees without killing the tree, which we did in some cases.

Q. (from Don Despain)—How did you distinguish older bear-feeding scars from fire scars?

A.—Bear scars tend to be longer (some may be 2 m long) and narrower than fire scars, but cause would often be difficult to distinguish on the very old scars we were sampling in this study. This would particularly be a problem with single scars. We felt, however, that multiple scars on the same tree would not likely be caused by bears, since once a portion of the tree was scarred the cambium would be dead and not attractive to bears. Once scarred by bears, trees could be easily reinjured by fire.

Q. (from Wyman Schmidt)—Did the bear stripping of the whitebark pine appear to be related to age, size, stand density, tree vigor, or other site or stand factors?

A.—The bear stripping was not specifically studied, but most stripped trees were greater than 25 cm in diameter and often the largest trees in a stand. It occurred in stands of varying density and topographic position. We do not recall any other relationship of bear stripping to site or stand factors.

INSECTS OF WHITEBARK PINE WITH EMPHASIS ON MOUNTAIN PINE BEETLE

Dale L. Bartos
Kenneth E. Gibson

ABSTRACT

*Few insects that live on whitebark pine (*Pinus albicaulis*) are considered pests or potential pests. Those that inhabit cones can cause reductions in reproduction of the tree by destroying seed crops. Decreases in food for animals ranging from squirrels to grizzly bears may also result.*

*A single insect species, mountain pine beetle (*Dendroctonus ponderosae*) (MPB), may cause serious damage to whitebark pine over much of its range by killing mature trees. Through periodic epidemic outbreaks, the resultant tree killing causes reductions in seed cones and so decreases food supplies for various animals. Excessive mortality of whitebark pine can lead to increases in other tree species, and decreases in whitebark pine, in some future stands.*

A survey of MPB damage in the whitebark pine zone was conducted in Yellowstone National Park, Gallatin National Forest, and Flathead National Forest from 1983 to 1988. Preliminary results show 22 to 44 percent of the whitebark pine had been killed by MPB during the recent past. Losses were strongly related to elevation—decreasing mortality with increasing elevation. Losses were heaviest in the lodgepole pine-whitebark pine ecotone. Implications of such losses are discussed.

INTRODUCTION

Whitebark pine (*Pinus albicaulis* Engelm.) occurs at high elevations in the mountainous west of North America (Arno and Hoff 1989). This is a long-lived tree that grows very slowly on moist to dry sites. Like other trees, the whitebark pine provides habitat for various insect species. Most of these insects do not have serious effects on whitebark pine. An exception is mountain pine beetle (MPB) (*Dendroctonus ponderosae* Hopkins [Coleoptera: Scolytidae]) which occasionally occurs in epidemic proportions. Insects associated with whitebark pine have not been studied in any detail and, therefore, revelant literature is quite sparse.

Seeds from whitebark pine are not only important for regeneration of the trees but are also important as a food source for various animals (grizzly bears to squirrels). Whitebark pine cones can be invaded by cone worms (*Dioryctria* spp. and *Eucosma* spp.) and by cone beetles (*Conophthorus* spp.), but these insects have been virtually unstudied. Other species than those reported in the literature have been observed (Dewey 1989), such as midges and a seed chalcid (*Megastigmus* spp.). Cone and seed insects would probably affect whitebark pine as they do other conifer species, for example, causing years of light cone crops following a heavy cone crop year. More detailed work on cone and seed insects would show their importance to the whitebark pine system.

Foliage insects can cause stress in attacked trees by causing a decline in their growth rate. Aphids (*Essigella gillettei* Hottes) are known to feed on needles; mealybugs (*Puto cupressi* Coleman and *P. pricei* McKenzie) are found on branches and trunks (Arno and Hoff 1989). Arno and Hoff (1989) also state that the lodgepole needletier (*Argyrotaenia tabulana* Freeman), which is very destructive in lodgepole pine stands, can also infest whitebark pine.

Several secondary beetles (*Ips, Pityogenes,* and *Pityophthorus*) are known to attack the boles of whitebark pine. The Monterey pine ips (*Ips mexicanus* Hopkins) and two Pityogenes (*P. carinulatus* LeConte and *P. fossifrons* LeConte) are reported to infest the bole of whitebark pine (Furniss and Carolin 1977). Bright (1968) working in British Columbia described two species of *Pityophthorus* (*P. aquilonius* Bright and *P. collinus* Bright) that are found in whitebark pine.

Mountain pine beetle is the most destructive bark beetle in western North America (Furniss and Carolin 1977) because it can kill apparently healthy trees. This is the one insect that has the most impact on whitebark pines. Between 1911 and 1942 there was widespread destruction of lodgepole pine (*Pinus contorta* Douglas) forests by MPB in Idaho and Montana. These outbreaks were at lower elevations and moved upwards into the whitebark pine zone where "ghostlike forests" were created by the numerous dead snags that resulted (Ciesla and Furniss 1975) in about 1937. A similar situation occurred on the Flathead National Forest (NF) of Montana in the 1970's where epidemics developed in the lodgepole pine forests and then moved into the whitebark pine zone (Arno and Hoff 1989).

There are several instances of whitebark pine being invaded by MPB from epidemic populations that occur in lower elevation lodgepole pine. Baker and others (1971)

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conducted a study in western Wyoming to see if this scenario held true. In situations where both lodgepole and whitebark pine existed together, MPB killed proportionally more lodgepole than whitebark pine. In part, Baker and others (1971) attributed this to phloem thickness with the larger diameter trees (those with thicker phloem) being taken. Another part of their study described how cooler temperatures at the higher elevations caused little mortality by MPB in either lodgepole or whitebark pine. In part, the colder temperatures at the higher elevations reduced MPB survival and therefore lessened the number of trees killed.

Crossover of MPB from one host species to another has been detailed by Amman (1982). It is generally believed that insects invade species similar to the ones in which they developed (Allee and others 1949). However, both Amman (1982) and Wood (1963) stated that this rule probably holds under endemic (low population levels) situations only; during "full blown" epidemics MPB will select any acceptable host. Thus, we observe the movement of MPB from lodgepole into whitebark pine in the ecotonal zone with further movement into pure whitebark pine stands when epidemic conditions exist throughout vast lodgepole pine stands at lower elevations (Parker 1973).

As just described, a variety of insects occur in whitebark pine; however, none have the impact that MPB does. Therefore, it is the purpose of this paper to detail the effect of MPB on whitebark pine with particular emphasis on the northern Rocky Mountain region. Recent past epidemics and current work will be used to complete the picture of the effect of MPB on the whitebark pine ecosystem.

RECENT HISTORY

To better understand the interrelationship of MPB and whitebark pine we can look at the infested acres in the Northern Region of the USDA Forest Service during the past 10 years. Particular interest will be placed on the Gallatin and Flathead National Forests and surrounding areas.

Infested areas were determined by using aerial sketch mapping. Usually, this method does not record low level (endemic) populations of MPB. Mountain pine beetle activity peaked in the Northern Region during 1981. The following acreage was reported as infested lodgepole pine (predominantly lodgepole pine but other species did occur): Gallatin National Forest, 455,000 acres; Beaverhead National Forest, 119,000 acres; Flathead National Forest, 209,000 acres; and Yellowstone National Park, 965,000 acres.

Our reference to whitebark pine stands means that whitebark pine does occur but is not necessarily the dominant species. There were 32,000 acres of whitebark pine infested with MPB in 1983 in the Gallatin National Forest. This acreage has declined precipitously with only 500 acres infested in 1986 and none since then. The MPB epidemic has probably "run its course" in this area.

Similar trends were observed on other areas adjacent to the Gallatin National Forest. At the turn of the decade, there were about 10,000 acres of MPB-infested whitebark pine reported for the Beaverhead National Forest; during the past several years no additional infested acreage was reported. A similar trend was observed on the Custer National Forest but of a lesser magnitude. In 1981, there were 1,600 acres infested with only 150 acres by 1986. Again, none have been reported during the last 2 years.

Yellowstone National Park is an area of special concern because of recent fires and the destruction of endangered grizzly bear habitat. Similar trends were observed there with 34,000 acres being infested in 1983, however, no acreage has been reported the last few years. There are small populations of MPB, however, in some limber pine (*Pinus flexilis* James) stands near Mammoth.

In 1980, MPB infestation on the Flathead National Forest was 96,500 acres of whitebark pine. Infestations of whitebark pine dropped to 1,500 acres in 1986 and to only 100 acres last year. There has been no new acreage of infested whitebark pine observed in Glacier National Park for the past 3 years, however, earlier in 1980 there were 15,000 acres reported for whitebark pine and 292,000 acres for lodgepole pine.

AREA DESCRIPTIONS

Between 1983 and 1988, on-the-ground surveys were conducted to determine the extent of MPB in whitebark pine and surrounding tree types. These determinations were made on three areas: Gallatin National Forest, Flathead National Forest, and Yellowstone National Park.

Gallatin National Forest

In 1983, 211 data collection points were established at selected sites on the Gallatin National Forest. Fifty-six distinct stands were selected within three elevational zones (5,400-8,500 ft). These collection points were located on the Hebgen Lake, Bozeman, and Gardiner Ranger Districts (fig. 1). Eleven stands were found at lower elevations, in which Douglas-fir (*Pseudotsuga menziesii* [Mirbel] Franco) dominated; 25 stands were found at midelevations, in which lodgepole pine dominated, and 20 stands were found at high elevations, in which whitebark pine dominated. Even in the low-elevation stands, lodgepole pine was a major component. All stands were selected where whitebark pine occurred and where MPB was active or had been active in the recent past.

Yellowstone National Park

In 1987, 30 data collection points were established within the whitebark pine zone in Yellowstone National Park. The stands selected were mixed lodgepole and whitebark pine and occurred at about 8,300 ft elevation. All collection points were in the southwestern portion of Yellowstone National Park just west of Yellowstone Lake. Due to lack of ground access into high-elevation whitebark pine stands and the observation that most past beetle activity was confined to lodgepole pine stands, data were not collected from these high-elevation stands.

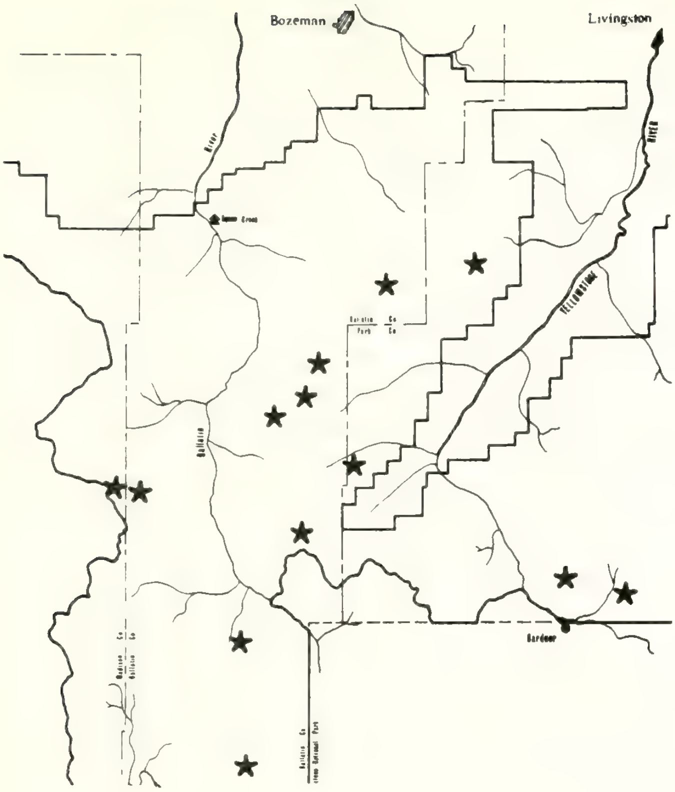

Figure 1—Map of Gallatin National Forest in southern Montana showing stand locations where sampling for MPB infestations was conducted during 1983.

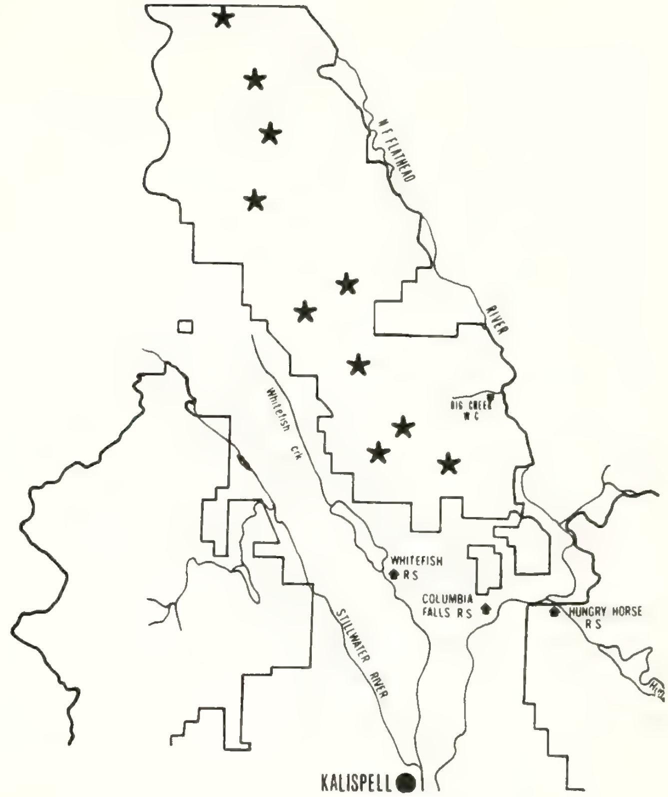

Figure 2—Map of Flathead National Forest in northern Montana showing stand locations where sampling for MPB infestations was conducted during 1988.

Flathead National Forest

To obtain data from a different geographical area, whitebark pine stands affected by MPB on the Flathead National Forest were sampled in 1988. Selected stands ranged in elevation from 5,500 to 6,600 ft, and were located exclusively on the Glacier View Ranger District in the Whitefish Mountain Range (fig. 2). Ten stands were visited—the northernmost was about 6 air miles south of the Canada-United States border and the southernmost was approximately 5 air miles north of Whitefish, MT. Number of plots per stand varied; a total of 80 plots was sampled. Stands were generally of mixed species; subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.) dominated, and all fit the criteria for the subalpine fir habitat type.

METHODS

Number and spatial arrangement of the plots established in each area were determined by the size and shape of the stand visited. Whenever possible, a minimum of 10 plots was located in each stand. These plots were generally located at 5-chain intervals along a compass line coinciding with the long axis of the stand. Occasionally, plots were established on parallel lines 5 chains apart. The initial plot in each series was located randomly, but it was at least 2 chains within the stand's boundary.

On each plot, various stand and site data were collected to relate ecological factors to pest-caused damage. At each plot center, a variable radius plot (BAF 10) was established using a Spiegel Relaskop R. Each "in" tree, equal to or greater than 5 inches d.b.h. (diameter breast height) was recorded by species and d.b.h. In addition, each tree was assigned one of the following "damage" codes:

0 = undamaged, healthy tree
1 = unknown mortality
2 = current year MPB-caused mortality
3 = previous year MPB-caused mortality
4 = older MPB-caused mortality
5 = unsuccessful MPB attack
6 = current year MPB strip attack
7 = older MPB strip attack
8 = current secondary beetle-caused mortality
9 = older secondary beetle-caused mortality
10 = secondary beetle strip attack
49 = spike top usually white pine blister rust
50 = other damage

Heights and ages were measured on the first two dominant or codominant trees of each species encountered on the plot. The observer was at the center of the plot and turned in a clockwise direction starting from the direction of travel; trees were recorded as they were encountered.

The center of the variable-radius plot also served as the center for a 1/300-acre (6.8-ft diameter) fixed-radius plot on which were collected regeneration data. Only the four "best" trees (greater than 6 inches tall and less than 5 inches d.b.h.) were recorded.

In addition to the stand data, the following site data were recorded for each plot: elevation, slope, and aspect. At each plot, a "downed fuel inventory" was conducted to assess the amount and size of materials contributing to the fuel load on the site. Observations regarding presence and abundance of various wildlife species were noted. Evidence of big game (trails, droppings, shed antlers) was recorded by species. In addition, habitats (such as snags or caves), sightings, or other indications of non-game mammals and birds were tallied. Sampling was done to determine the amount (on a dry weight basis) of understory vegetation as a critical component of the system.

RESULTS AND DISCUSSION

The 1988 distribution map of MPB activity in the Northern Region (fig. 3) shows the greatest intensity of tree killing by MPB to occur in the northwestern part of Montana near the Canadian border. Mountain pine beetle activity is strongest in the lodgepole pine type with very little recorded in the ponderosa pine, western white pine, or whitebark pine type (fig. 4). One might say that there is nothing to worry about concerning the whitebark pine; however, Amman (1982), Parker (1973), and Wood (1963) stated there is strong evidence that any whitebark pine stands that occur above lodgepole pine stands could definitely be in danger of attack or devastation. Even if the whitebark pine stands are not in close association with lodgepole pine they are still at risk because infestations can occur during warmer than average years in the absence of lodgepole pine infestations (Baker and others 1971).

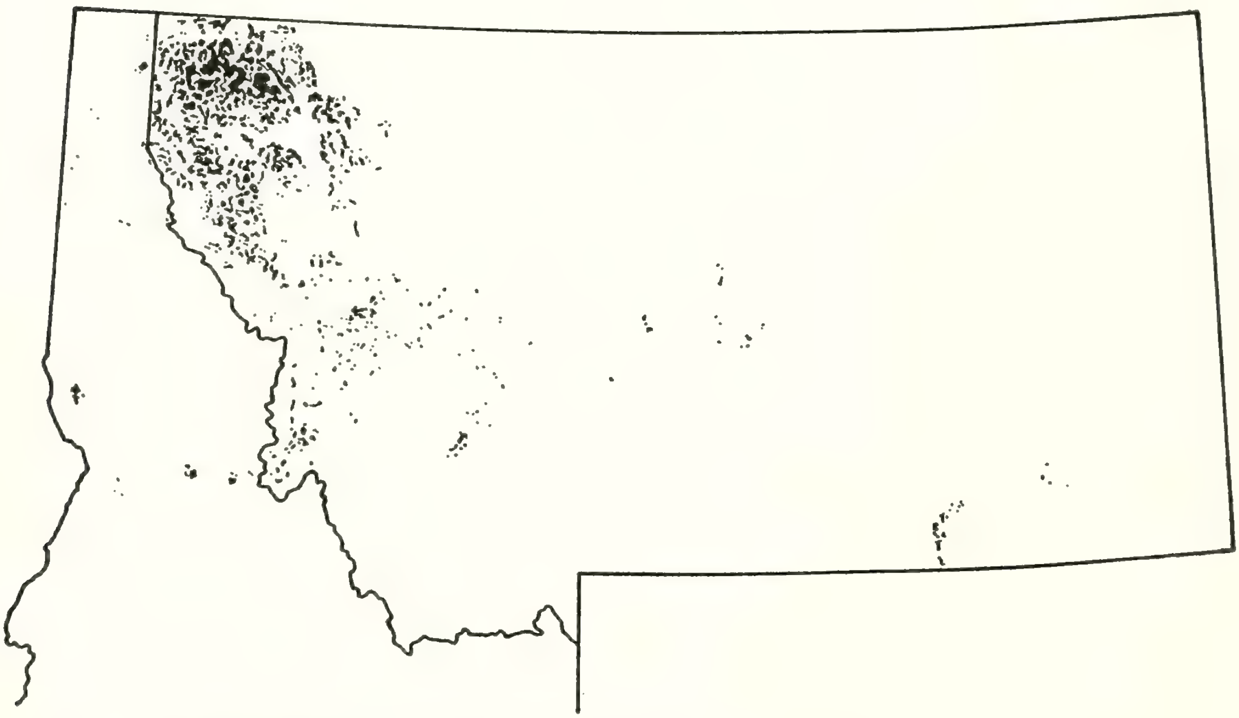

Figure 3—A map of the Northern Region showing the location of MPB infestations for 1988.

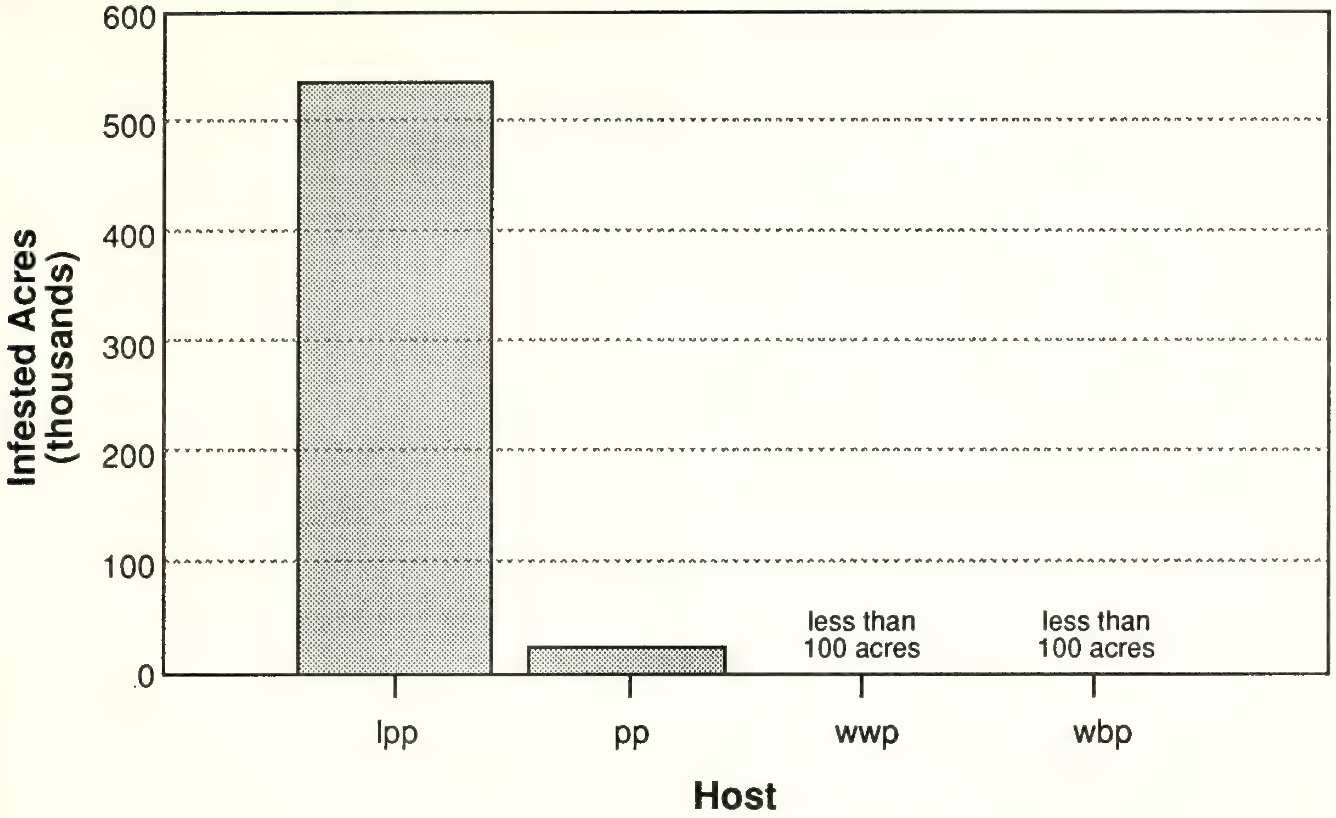

Figure 4—Acreage of MPB infestations in the Northern Region for 1988 for four host species: lodgepole (lpp), ponderosa (pp), western white (wwp), and whitebark pine (wbp).

Gallatin National Forest

Surveys during 1983 found MPB and unknown agents were the major killing agents of both lodgepole pine and whitebark pine across all 56 stands sampled (table 1). Mortality of lodgepole pine varied between 10 and 62 percent for the various size classes considered. Highest mortality was observed in the largest trees, 12 inches and larger d.b.h., while the least mortality was seen in the 5- to 9-inch d.b.h. category.

Similar trends were observed in the whitebark pine on the Gallatin National Forest (table 1). Where whitebark pine dominated, the most mortality occurred in the largest trees—23 percent of the 12 inch and larger. Even at the lowest elevations sampled, where Douglas-fir dominated, there was 60 percent mortality, caused by secondary beetles, of the 5- to 9-inch d.b.h. whitebark pine trees.

It should be noted that less than 10 percent of the MPB attacks at the time of the survey were current which shows most MPB activity occurred prior to the sample year and supports the fact that MPB activity peaked on the Gallatin National Forest in 1981. This information further substantiates what Arno and Hoff (1989), Ciesla and Furniss (1975), and Parker (1973) observed of outbreaks occurring in the lower lodgepole pine zone and moving up into the whitebark pine zone.

With almost a quarter of the dominant trees being killed in the whitebark pine zone, what effect will this mortality have on future forests? There will definitely be a reduction in the cone crop for the immediate future because the most mature trees were killed. It is safe to say that whitebark pine reproduction might suffer some and that one food source (pine nuts) for animals will be diminished. There may be a shift in the ecotonal zone between lodgepole pine and whitebark pine as a result of this mortality. Will the whitebark pine zone expand into the lower lodgepole pine area or vice versa? It is conceivable that the remaining whitebark pine may become more vigorous because of the "natural thinning" by MPB of both whitebark and lodgepole pine.

Yellowstone National Park

In our survey of Yellowstone National Park, MPB-caused mortality was not observed for the sample year or previous years. Accessibility to other high-elevation whitebark pine stands was not possible, therefore, the survey was limited. Furthermore, it was observed that most of the past beetle activity was confined to lower elevation lodgepole pine stands. Almost a million acres of lodgepole pine was infested in Yellowstone National Park in 1981. This was one of the main contributing factors to the tremendous fuel loads that existed in the National Park for the fire season of 1988.

Table 1—Summary of whitebark pine and lodgepole pine mortality due to mountain pine beetle for Gallatin National Forest for 1983

Elevational zones	No. of stands surveyed	Dominant tree species	D.b.h. classes 5-8.9 inch	9-11.9 inch	12 + inch
Killing agent/species[1]			*Percent mortality*		
Low elevation	11	Douglas-fir			
MPB/LPP			14.5	38.4	61.7
SEC/LPP			0.0	2.2	0.6
UNK/LPP			16.0	3.8	0.0
Total LPP			30.5	44.4	62.3
SEC/WBP			59.5	0.0	0.0
Mid elevation	25	Lodgepole pine			
MPB/LPP			16.3	38.9	53.2
SEC/LPP			6.1	2.1	1.6
UNK/LPP			2.2	0.6	1.5
Total LPP			24.6	41.6	56.3
High elevation	20	Whitebark pine			
MPB/LPP			0.0	5.5	39.3
SEC/LPP			5.6	4.3	5.0
UNK/LPP			6.9	0.0	0.0
Total LPP			12.5	9.8	44.3
MPB/WBP			0.8	5.3	19.1
SEC/WBP			1.4	5.0	2.2
UNK/WBP			0.7	1.7	2.0
Total WBP			2.9	12.0	23.3

[1]MPB = mountain pine beetle
SEC = secondary beetles
UNK = unknown agent
LPP = lodgepole pine
WBP = whitebark pine.

Flathead National Park

Stands were sampled in northern Montana to give a more complete picture of the effects of MPB on whitebark pine in the Northern Region. A summary of 80 plots that were sampled (table 2) shows a range of live whitebark pine 5-inch d.b.h. and larger varied between 1 tree/acre to 87 trees/acre. An average of 27 percent of the stand was composed of live whitebark pine and this varied between 1 and 63 percent for the 10 stands sampled. Percent mortality for the whitebark pine was between 14 and 97 percent with most of the kill occurring prior to 1987. Only a little mortality was recorded for 1987 and hardly any for 1988. This helps validate what was observed on the Gallatin National Forest and in Yellowstone National Park.

Effects of MPB on whitebark pine was directly connected to the peak infestation for the Region. Most of the mortality seen occurred between 1981 and 1987. If MPB infestations continue to decline, the remaining whitebark pine in the Northern Region will not likely succumb to MPB, at least in the near future.

Miscellaneous Observations

Total understory vegetation (current growth of shrubs, forbs, grasses, and grasslike species) was sampled to determine, in part, fine fuels that exist in the stands. On the Gallatin National Forest understory vegetation was sparse with values ranging from 166 to 1,217 lb/acre. Farther north on the Flathead National Forest, understory growth was considerably more with values of 1,090 to 1,748 lb/acre. Understory values of 166 lb/acre imply impoverished sites; and 1,748 lb/acre imply moderately stocked understory.

In the 10 areas sampled on the Flathead National Forest, most regeneration observed was subalpine fir. Next in occurrence was Engelmann spruce. On only four of the 10 areas sampled was whitebark pine regeneration noted, and then it was always in the minority. We did not observe whether this was due to lack of seeds or merely a successional pattern typical of subalpine fir habitat types.

Table 2—Summary of whitebark pine (WBP) mortality due to mountain pine beetle (MPB) for Flathead National Forest for 1988

Stand number	Green WBP 5 inch+	1988 MPB attacks	1987 MPB attacks	Older MPB attacks	Stand green WBP	WBP mortality	Secondary attacks	Blister rust damage
	Number/acre				Percent		Number/acre	
1	25.6	0.0	0.0	8.0	63	24	0.0	0.3
2	38.8	0.0	0.0	15.6	52	29	0.0	4.8
3	48.3	0.0	32.3	136.8	51	78	34.9	9.1
4	9.6	1.2	0.0	0.4	13	14	0.0	0.0
5	86.9	0.0	14.2	32.7	44	35	8.1	0.0
6	29.0	0.0	35.0	8.3	13	60	0.0	20.8
7	20.5	0.0	19.9	22.5	11	67	0.0	0.0
8	1.2	0.0	9.9	29.3	1	97	0.0	0.0
9	9.8	0.0	2.3	28.1	6	94	0.0	0.0
10	6.1	0.0	0.0	56.0	4	90	17.0	0.0
Average	27.3	0.1	13.4	36.2	27	65	6.5	4.7

CONCLUSIONS

In the Northern Region, whitebark pine was killed as a result of the epidemic MPB populations that peaked in this area during the early 1980's (an exception was Flathead National Forest, which peaked in 1986). Most information we have suggests that whitebark pine stands were infested by MPB populations originating in lower elevation lodgepole pine stands. This conclusion is substantiated by the literature. However, MPB can, and sometimes does, kill whitebark pine in the absence of adjacent infestations in lower elevation lodgepole pine stands.

For the most part, if we want to reduce mortality in whitebark pine stands it appears that we need to suppress MPB populations in lodgepole pine stands that occur at lower elevations. Thinning of lodgepole pine stands on the Kootenai, Lolo, and Flathead National Forests shows basal area reductions can significantly reduce losses to MPB (McGregor and others 1987). Such population reductions by stand manipulation should reduce the likelihood of MPB outbreaks in the higher elevation whitebark pine stands.

We suggest the following as ways of better understanding the interrelationship of pests and whitebark pine:

1. Monitor the effects of insect pests (not just MPB) in whitebark pine stands in other geographical locations in the Region.
2. Obtain more accurate information on the impacts of cone and seed pests on whitebark pine.
3. Gain a better understanding of the association between MPB and secondary bark beetles in whitebark pine stands.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from David Charlet)—Is work being done on improving rearing techniques of predatory wasps for introduction as a means of biological control?

A.—The only parasitic wasp of importance affecting MPB populations is the Braconid, *Coeloides brunneri* Viereck. It may exert a small amount of control on endemic beetle populations, however, at epidemic levels, it is probably of little consequence. Artificial rearing of this wasp has not been successful. To our knowledge, no work is currently being done in that area. Efforts are better spent trying to manipulate the host rather than the pest populations.

Q. (from Ron Lanner)—How much is known about the effects of white pine weevil on *Pinus albicaulis*?

A.—In our experience, the only host of the white pine weevil (*Pissodes strobi* Peck) in the Intermountain West is Engelmann spruce. Lodgepole pine is affected by a closely related species, *P. terminalis* Hopping. We have never observed, nor seen recorded in the literature, *P. terminalis* infesting whitebark pine.

Q. (from Jim Jacobs)—(a) Is whitebark pine a preferred host for beetles or do they choose it when all else is consumed, and is whitebark pine susceptible to blue stain fungus? (b) What percent of seeds are consumed by worms and do you think nutcrackers can recognize them?

A.—(a) Whitebark pine is not the *most* preferred host of MPB, but it will readily infest it, as it does virtually any pine species within its range. In order of preference (as judged by occurrence of damage caused), the beetles' choice of host is probably lodgepole pine, ponderosa pine, western white pine, whitebark/limber pine, and ornamental (exotic) pines. This scenario may be only applicable in the Intermountain West; in the Sierra Nevada, this list may vary somewhat. Yes, whitebark pine is susceptible to blue stain fungi. (b) We have not surveyed cone crops in whitebark pine stands nearly enough to estimate what proportion of the seeds may be affected by coneworms, cone beetles, midges, or seed chalcids. All, however, have been recorded as affecting whitebark pine seeds. This is an area where work is sorely needed. We would not hazard a guess as to whether or not nutcrackers can recognize infested seeds.

Q. (from Anonymous)—How much of the whitebark pine mortality from MPB occurs in endemic situations versus epidemic? (Also) can beetles overwinter in whitebark pine stands? What effect does tree vigor/phloem thickness have on susceptibility to beetle attack?

A.—We have little information on endemic MPB populations in whitebark pine stands. Beetles do kill some older, weaker individuals in endemic situations, but it is likely part of the "background" or naturally occurring mortality. Yes, MPB can overwinter in whitebark pine stands. Tree vigor—as exhibited by young healthy trees—is important in protecting them from endemic beetle populations. It is of less importance in full-scale epidemics. Also, phloem thickness is critical to the beetle as it is the food of the developing larvae. Trees with phloem too thin to support developing broods are seldom attacked.

DISEASES OF WHITEBARK PINE WITH SPECIAL EMPHASIS ON WHITE PINE BLISTER RUST

Ray Hoff
Susan Hagle

ABSTRACT

Whitebark pine (Pinus albicaulis) *has few endemic diseases that do much harm. White pine blister rust* (Cronartium ribicola *J. C. Fisch. ex Rabenh.), an exotic disease brought here from Europe, is the most damaging disease. It is epidemic over most of the range of whitebark pine.*

There have been 23 diseases reported for whitebark pine, including stem and branch cankers, needle casts, seed and cone diseases, stem and root decays, and dwarf mistletoes. Significant damages from most diseases have been observed only in localized areas. White pine blister rust is the only disease that is widespread and damaging over most of the range of whitebark pine, with the exception of high-dry areas such as in Yellowstone National Park.

Pruning and excising cankers are good management options for saving trees infected by white pine blister rust, but only on moderately hazardous sites. On high-hazard sites, the only option is to utilize resistance. Resistance is common in whitebark pine. Several methods for using resistance to restock decimated areas are presented.

INTRODUCTION

Whitebark pine (*Pinus albicaulis* Engelm.) grows over a large geographic area, but within this area it is restricted to a fairly narrow ecological zone (Arno and Hoff 1989). However, forests adjacent to whitebark pine habitats vary widely. On the coast, adjacent forests are wet and warm; in the Rocky Mountains they are dry and cold. Consequently, whitebark pine is subjected to many different pest problems. The rate of infection by white pine blister rust appears to depend on the amount of inoculum produced in adjacent forests. If those forests are not conducive to the disease, then there is little infection. Some pathogens, such as the canker fungus *Lachnellula pini* and the foliar fungi *Bifusella saccata* or *Herpotrichia coulteri*, prefer high-elevation sites on which whitebark pine grows.

Nonetheless, except for local epidemics that occur from time to time, whitebark pine is relatively free of diseases. The only widespread and serious disease is white pine blister rust (caused by *Cronartium ribicola* J. C. Fisch. ex Rabenh.). The disease was introduced to western North America in 1910.

The purpose of this paper is to review both known and potential diseases of whitebark pine, with major emphasis placed on white pine blister rust, and offer recommendations for management of whitebark pine that would aid its survival in rust-decimated stands.

NONRUST DISEASES OF WHITEBARK PINE

Other than white pine blister rust, the most damaging pathogen is probably limber pine dwarf mistletoe, (*Arceuthobium cyanocarpum* Coulter & A. Nels.). Numerous diseases have been reported afflicting whitebark pine (Hagle and others 1987; Hepting 1971; Hiratsuka and Funk 1976; Smith 1978). Some, particularly old-growth diseases such as heartrots or butt rots, are likely to be less important in managed stands. Others, like annosus root rot, may become more damaging in managed stands. Seed and cone pathogens such as *Siroccocus* blight, may become important if artificial regeneration is used. Both pathogens known to cause damage and those considered potentially damaging to whitebark pine are presented in table 1.

STEM AND BRANCH CANKERS

Gremmeniella abietina (*Gremmeniella abietina* (Lagerberg) Morelet =*Scleroderris lagerbergii* Gremmen =*Crumenula pinea* (Karst.) Ferd.& Jorg.; anamorph =*Brunchorstia pinea* (Karst.) Hoehn.) has aroused a great deal of interest since its discovery in Ontario, Canada, and the northeastern United States. This fungus was found to cause serious damage to pine plantations in those areas. Mortality rates exceeding 50 percent were measured in many young pine plantations (Skilling and Cordell 1966). The fungus had long been known to cause similar damage to plantations in Europe.

Three strains of the fungus are now known to occur in North America (Skilling and others 1984). The one referred to as the "North American strain" has been present at least since the early 1950's. This fungus has a

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Table 1—Pathogens of whitebark pine

Pathogen	Disease or other name
Stem and branch cankers	
Cronartium ribicola	White pine blister rust
Gremmeniella abietina	*Scleroderris lagerbergii*
Lachnellula pini	*Dasyscypha pini*
L. agassizii	
L. arida	
L. flavovirens	Branch dieback
Atropellis piniphila	
Needlecasts and blights	
Bifusella saccata	
Lophodermella arcuata	
Bifusella linearis	
Lophodermium nitens	
Lophodermium pinastri	
Herpotrichia coulteri	Brown felt blight
Seed and cone diseases	
Sirococcus strobilinus	*Sirococcus* blight
Calocypha fulgens[1]	Seed or cold fungus
Stem and root decays	
Perenniporia subacida	Feather root rot
Phaeolus schweinitzii	Root and butt rot
Heterobasidion annosum	*Annosus* root rot
Armillaria ostoyae	*Armillaria* root rot
Dwarf mistletoe	
Arceuthobium cyanocarpum	Limber pine dwarf mistletoe
A. tsugense	Hemlock dwarf mistletoe
A. americanum	Lodgepole pine dwarf mistletoe
A. laricis	Larch dwarf mistletoe

[1]Not reported infecting whitebark pine but high potential for damage expected, based on ecology.

relatively narrow host range, infecting only the genus *Pinus*. Cankers caused by this strain are generally restricted to the lower branches of a tree and are usually damaging only to small trees.

The fungus referred to as the "European strain" appears to have greater potential for damage. It has been recognized as a distinct strain in the northeastern United States since the early 1970's. It has a broad host range including *Pinus*, *Picea*, *Abies*, *Larix*, *Tsuga*, and *Pseudotsuga*. Cankers occur at all heights in trees, on both stems and branches. Infection can take place at any age.

A third strain has been described that has characteristics intermediate between the North American and the European. The relationship between the North American and European strains of *G. abietina* is not understood, but it appears that they have been separate strains for a considerable time, based upon the great differences in ecology.

One collection of *G. abietina* on whitebark pine has been reported. This collection was made at Apex Mountain near Penticton, BC, in 1968. Hiratsuka and Funk (1976) speculated that the fungus collected on whitebark pine was an endemic form of the pathogen with little potential for serious damage.

Because *G. abietina* is known to have considerable potential for damage and has the ability to infect whitebark pine, it should be considered a potentially damaging parasite. Care should be taken to avoid moving the European or intermediate strains of the fungus into whitebark pine habitats. With the current interest in active management of whitebark pine, there is potential for infection of nursery-grown seedlings possibly leading to transport of the pathogen into natural whitebark pine stands.

Lachnellula pini (Brunch.) Dennis = *Dasycypha pini* (Brunch.) Hahn & Ayers has a circumpolar distribution at high elevations and northern latitudes. It causes a resinous canker of whitebark pine that has been confused with white pine blister rust in the Pacific Northwest. Stillinger (1929) surveyed western white pine stands in the Inland Empire and found that those most heavily infected by *L. pini* occur at relatively high elevations—4,500 to 6,000 ft.

Hahn and Ayers (1934) recorded three collections of *L. pini* on whitebark pine in British Columbia. These were in Mt. Revelstoke National Park, 4,000 to 5,000 ft elevation; Flat Creek, east of Revelstoke at 6,000 to 7,500 ft elevation; and D'Arcy, 3 miles west at 6,000 ft elevation. These observations were consistent with results of growth studies in which they found optimal *in vitro* growth of *L. pini* occurred at temperatures between 38 and 42 °F. They concluded that "we may be dealing with a parasite peculiarly specialized as regards the necessary environment for its existence, and for this reason limited in its present distribution."

Lachnellula pini is not observed to grow beyond the canker after death of the branch or stem. Fruiting is localized in the immediate area of the canker. It is not, however, an obligate parasite because abundant fruiting continues even after the branch or stem has died.

Stillinger (1929) reported high levels of damage to western white pine stands caused by *L. pini* cankers. Whitebark pine was not included in his survey, but whitebark pine may be similarly affected on high-elevation sites in the Inland Empire.

Three other species of *Lachnellula* are known to be locally damaging to whitebark pine stands. *Lachnellula agassizii* (Ber. & Curt.) Dennis is parasitic, causing cankers on branches and stems (Smerlis 1973). The anamorph of this species, *Naemospora*, is observed fruiting at canker margins along with *L. agassizii*. *Lachnellula arida* (Phill.) Dennis is also a parasite that causes cankers on branches and stems (Funk 1981). *Lachnellula flavovirens* (Bres.) Dennis is considered to be a facultative parasite that causes cankers and dieback of branches (Frajo-Apor 1976; Smerlis 1973).

Atropellis piniphila (Weir) Lohman & Cash was described by Lohman and Cash (1940) as causing a canker on several pine species including whitebark pine. This fungus is best known from lodgepole pine on which it causes extensive damage in the northern Rocky Mountains of the United States and Canada (Hopkins 1985; Lightle and Thompson 1973). Black radial staining occurs in the wood adjacent to cankers, and the bark external to cankers adheres tightly to the stem thus creating problems for pulping. Mortality is a secondary concern, although mortality rates can be high in some severely infected stands. At greatest risk for mortality are young trees growing on sites with histories of *Atropellis* damage.

NEEDLECASTS AND BLIGHTS

Bifusella saccata (Darker) Darker has been reported on whitebark pine and limber pine (*P. flexilis*) (Staley 1964). It is found at elevations above 9,000 ft on whitebark pine in the southern Sierra Nevada (Bega 1979). It is reported as rarely occurring on whitebark pine in British Columbia, where it is observed to fruit on dead tips of green needles (Funk 1985).

Lophodermella arcuata (Darker) Darker was reported to cause a needlecast of whitebark pine in British Columbia (Hunt and Ziller 1978). Severe defoliation of a sugar pine (*P. lambertiana* Dougl.) plantation greatly reduced terminal growth (Burleigh and others 1982). Within a heavily infected plantation, individual trees that were apparently resistant were found. The disease was damaging in occasional, isolated trees in limber pine stands in Colorado (Staley 1964).

Bifusella linearis (Peck) Hoehn. is reported to cause a common needlecast disease of whitebark pine (Bega 1979; Funk 1985; Hunt 1981). Two- to 3-year-old needles are killed and cast. Because the fungus is restricted to older foliage, it is not considered to cause a serious disease.

Lophodermium nitens Darker is a common needlecast-causing fungus on whitebark pine (Darker 1932; Funk 1985; Hunt 1981). Hunt (1981) considered the fungus to be a weak pathogen, attacking only the older foliage.

Lophodermium pinastri (S. ex H.) Chev. is also found on whitebark pine needles, but is probably present as a saprophyte.

Brown felt blight caused by *Herpotrichia coulteri* (Peck) Bose kills snow-covered foliage and causes branch dieback or, in the case of seedlings, death. This disease is widespread and common owing to the snowpack found in whitebark pine habitats.

SEED AND CONE DISEASES

Sirococcus strobilinus Preuss causes a seed-borne disease of many conifers including whitebark pine. The disease damages seedlings in nurseries and in natural stands. Losses in nurseries are due both to seedling mortality and to culling for deformity. The fungus is thought to infect fully formed seed, but the mechanism is not known (Sutherland 1987b). Nursery production of whitebark pine is likely to be accompanied by some level of damage from *Siroccocus* blight. The frequency of occurrence of this disease in natural whitebark pine regeneration is not known.

Calocypha fulgens (Pers.) Boud. (anamorph = *Geniculodendron pyriforme* Salt) referred to as the seed or cold fungus, causes pre-emergence seed losses in numerous conifer species including eastern white pine (*P. strobus* L.). This seed-borne fungus spreads from diseased to healthy seeds during cold periods. The mycelium of the fungus grows through forest duff. Cones that contact the duff are subject to infection. Thus cones on the ground or in squirrel caches or, perhaps in the case of whitebark pine, seeds cached by nutcrackers, may be infected.

Sutherland (1987a) reported losses of 25 percent of stored seed of spruces, Douglas-fir (*Pseudotsuga menziesii* Mirb.), and grand fir (*Abies grandis* [Dougl.] Lindl.) in British Columbia due to this fungus. In Ontario, bareroot nurseries' seed germination of numerous conifer species was reduced by as much as 98 percent. Cool soil conditions were most commonly associated with high losses to *C. fulgens*. Rates of isolation of the fungus from spruce seedlots in Washington and Oregon were sufficiently high for Sutherland to conclude that the disease has potential to impede natural regeneration of Engelmann spruce (*Picea engelmannii* [Parry] Engelmann) in certain areas of the western United States (Sutherland 1987a).

Fruiting bodies of this fungus are widespread and common in the early spring in the Rocky Mountains and Pacific Northwest (Tylutki 1979). The habitat requirements of *C. fulgens* and its potential for damage in both natural stands and nurseries may have serious implications for whitebark pine regeneration.

STEM AND ROOT DECAYS

Perenniporia subacida (Pk.) Donk and *Phaeolus schweinitzii* (Fr.) Pat. have been locally damaging in old stands of whitebark pine. *Phellinus pini* (Thore:Fr.) Pilat. causes a heartrot of whitebark pine that is also common in some locations. All these pathogens are likely to be significant only in old stands. Regeneration of whitebark pine stands is not likely to lead to significant carryover or intensification of damage from these pathogens.

Heterobasidion annosum (Fr.) Bref. = *Fomes annosus* = *Fomitopsis annosa*; anamorph = *Spiniger meineckellus* (A. J. Olson) Stalpers is another matter. This fungus is one of the most aggressive root pathogens; it responds to stand harvest by infecting cut stumps, presenting even greater problems with each succeeding generation of susceptible hosts. Numerous environmental factors play a role in determining whether *H. annosum* will increase with timber harvest and whether damage from this pathogen will continue over the life of the stand. The frequency of root infection in the existing stand may greatly influence the potential for damage in a succeeding rotation. *Heterobasidion annosum* is a common pathogen of subalpine fir (James 1979). It causes direct mortality of infected trees or, perhaps more commonly, it rots the tap root and develops into a butt rot. In either case, infected roots of subalpine fir can serve as a food and inoculum base for infection of whitebark pine. The frequency with which whitebark pine is infected by *H. annosum* in natural stands has not been investigated. Mature western white pine were commonly found to have root and butt rot caused by *H. annosum* before white pine blister rust lead to their wholesale removal from forest stands in the Inland Empire (Ehrlich 1939).

Direct stump surface infection by spores of *H. annosum* is considered a major means of spread and intensification of this fungus in forest stands (Edmonds and others 1984; Hunt and others 1976; Rishbeth 1951; Wallis and Ginns 1976). Temperature and moisture conditions in whitebark pine habitats are likely to be suitable for both sporulation and infection by *H. annosum*. Spring and fall temperature and moisture conditions are generally regarded as best for growth, sporulation, and infection in north temperate zones where *H. annosum* is known to be damaging.

Soil characteristics have been found to play a great role in determining the longevity of stand damage from this fungus following tree cutting in the southeastern United States. Soils with poor internal drainage and high seasonal water tables were found to not support long-term infestations by *H. annosum* (Anderson and others 1980; Froelich and others 1977). The fungus is believed to have limited tree-to-tree movement in such soils. Trees that are immediately adjacent to infected stumps may be killed at a high rate in the decade following tree cutting, but the fungus spreads little to other live trees.

Heterobasidion annosum is mentioned as a known pathogen of whitebark pine by Hepting (1971), but no references to published reports of the fungus infecting this tree species are offered. Webb and Alexander (1985) did not list whitebark pine among the known hosts for *H. annosum*. Root pathogens of whitebark pine have probably received less attention than other, more readily observable, pests of this species. With this in mind, it is prudent to regard the fungus as a pathogen that will almost certainly infect whitebark pine and may have considerable potential for damage in managed stands.

Likewise, *Armillaria* root rot has been listed as a disease of whitebark pine without reference to the extent or severity of the infection. *Armillaria ostoyae* (Romagnesi) Herink is not specifically known to be a pathogen of whitebark pine, but can be assumed to infect this species because it is generally considered to be the predominant pathogenic *Armillaria* on western conifers.

Whitebark pine habitats are outside the temperature/moisture combination range that we normally consider to be *Armillaria*-prone, but subalpine firis occasionally damaged by this pathogen. The frequent association of whitebark pine with subalpine fir probably exposes whitebark pine to inoculum of *A. ostoyae*. *Armillaria* may result in locally important damage, but it is more likely to be an infrequent killer of scattered, individual trees.

DWARF MISTLETOE

Limber pine dwarf mistletoe (*Arceuthobium cyanocarpum* Coulter & A. Nels.) infects and sometimes kills whitebark pine. This parasitic plant occurs in scattered locations from the southern Sierra Nevada to the mountains of Montana, Idaho, Wyoming, Colorado, Utah, and Nevada (Hawksworth and Wiens 1972). One location is known in Oregon, in Deschutes County (Hawksworth and Wiens 1984).

Limber pine and Great Basin bristlecone pine (*P. longaeva* D. K. Bailey) are the principal hosts of this species of dwarf mistletoe; whitebark pine is considered both a primary (Mathiasen and Hawksworth 1988) and secondary (Hawksworth and Wiens 1972) host. Other unusual hosts include western white pine (*P. monticola* Dougl.), ponderosa pine (*P. ponderosa* Laws.), Rocky Mountain bristlecone pine (*P. aristata* Engelm.), foxtail pine (*P. balfouriana* Grev. & Balf.), and mountain hemlock (*Tsuga mertensiana* [Bong.] Carr.) (Hawksworth and Wiens 1972; Hawksworth and Wiens 1984; Scharpf 1984).

Heavy mortality of whitebark pine resulting from limber pine dwarf mistletoe infections has been reported only from Mount Shasta, CA, where Cooke (1955) referred to infested stands as "ghost forests." Stands in this area were surveyed by Mathiasen and Hawksworth (1988). They had an average of 96 percent of whitebark pine infected with 58 percent dead. Most of the dead trees had evidence of past heavy dwarf mistletoe infection.

Arceuthobium tseugense (Rosendahl) G. N. Jones (hemlock dwarf mistletoe) is known to infect whitebark pine in the Crater Lake region of Oregon where it causes considerable damage (Hawksworth and Wiens 1972). *Arceuthobium americanum* Nutt. ex Engelm. occasionally infects whitebark pine when it grows in association with infected lodgepole pine. Likewise, *A. laricis* (Piper) St. John is known to occasionally infect whitebark pine when it grows among infected western larch (Hawksworth and Wiens 1972).

WHITE PINE BLISTER RUST

The disease that has the most impact on whitebark pine is white pine blister rust. Blister rust is a stem rust limited to the white pines. It is native to Eurasia, and all species of white pines on those continents are moderately to highly resistant to the fungus. However, it is exotic to North America, and it follows that all North American white pines are highly susceptible. Whitebark pine appears the most susceptible.

The white pine blister rust fungus was brought to western North America in 1910, arriving with a boatload of blister rust-infected eastern white pine (*Pinus strobus* L.). The seedlings were shipped by the nurseries of Pierre Sebire and Son, Ussy, France. The point of introduction was Point Grey, near Vancouver, BC. The disease was not noticed until 1921 (Boyce 1922). In the fall of that year, blister rust was observed in several stands in southwestern British Columbia and northwestern Washington. By 1922, cankers were found 100 mi north of Vancouver, in eastern British Columbia, and eastern Washington. By 1927, cankers were observed near the southern limit of western white pine in Idaho.

To get a better idea of just when the fungus entered a specific site, Lachmund (1926a) reconstructed the early history by dating backwards from cankers—something that is fairly easy to do and usually correct within a year or two. The evidence is good that the rust infected trees 130 mi northwest of Vancouver, 110 mi north, and 70 mi east, by 1913. In 1917 or 1918, the rust infected trees of the interior pine regions, including the Canoe, Revelstoke, and Beaton regions of British Columbia, Butte Inlet, 150 mi north of Vancouver, BC, and 100 mi to the south in the Puget Sound region. Further, the infection observed in Idaho in 1927 was dated to a 1923 infection. So, in just 13 years, blister rust had become established throughout the range of western white pine and in a high proportion of the range of whitebark pine. By 1965, the fungus seemed to have reached the ecological limit of its range.

The first infected whitebark pine was reported in the University of British Columbia Arboretum (Davidson 1922) and in a botanical garden in England (Spaulding 1923). Infection of whitebark pine, in a natural setting, was first observed in the coast range of British Columbia, 100 mi north of Vancouver (Lachmund 1926b). This observation was in a mixed stand of whitebark pine and western white pine. At least at this site, whitebark pine appeared to be seven to 10 times more susceptible than western white pine. Childs and others (1938) reported infection of whitebark pine in the Mount Hood area of Oregon, and Gynn and Chapman (1951b) found cankers in Yellowstone National Park that dated back to a 1945 infection.

The first thing foresters did when they discovered the disease was to destroy the trees that were infected. But with a fast-moving disease like this one, it became obvious that this approach would not work. The fungus also requires an alternate host to complete its life cycle. It must go from pine to currants or gooseberries (*Ribes*) and then back to pine. No problem—just remove the *Ribes* bushes. And so they tried! Table 2 shows the number of bushes removed from eastern Washington, Idaho, Montana, and Wyoming from 1923 to 1965 (USDA 1953, 1965).

In 1965, foresters gave up attempts to eradicate *Ribes* bushes. Most *Ribes* spp. are high survivors and, thus, not easy to get rid of. Next, chemicals were used on the pine host. Some at first seemed to hold promise of killing the fungus, but these too ended up not working well enough. The outlook for white pines was bleak.

Impact of Blister Rust on Natural Stands

Table 3 lists the published data, including survey data from official Forest Service files (Northern Region), that we found on the infection level of blister rust in natural stands (Bedwell and Childs 1943; Berg and others 1975; Brown 1966; Carlson 1978; Gynn and Chapman 1948, 1952a, 1952b; Toko and Dooling 1968). Figure 1 indicates locations of these stands. These data are not current; most of the surveys were conducted at least 20 years ago. Also, in most cases the ages of the stands were not indicated. Stand age greatly influences rate of infection, so comparisons of rates of infection without consideration of stand age are not very meaningful. Observations indicate that the infection levels and mortality in northern Idaho and Montana may be more severe now than they were in the 1960's. These old survey data do substantiate the general observation that whitebark pine is highly susceptible to blister rust and is impacted heavily where environmental conditions are conducive to the blister rust. They also indicate that damage can be very light where environmental conditions are not conducive to the disease. Further, it seems reasonable to conclude that the degree of infection on whitebark pine decreases southward for all parts of its range—throughout the Cascade-Sierra Nevada chain, the Bitterroot Mountains, and along the Continental Divide of the Rocky Mountains.

This is especially evident in Yellowstone National Park where there have been extensive surveys (table 4), even in areas where there are substantial populations of *Ribes* (Toko and Dooling 1968). This limitation is probably due to a somewhat dry and perhaps cold climate, together with a decrease in low elevation sources of inoculum.

Carlson (1978) reported survey results from 29 stands in Yellowstone National Park. Four of 29 stands were found to have blister rust infections. Rate of infection ranged from 0 to 6 percent of trees. Nine stands were found to have *Ribes* populations. *Ribes* importance, expressed as: (*Ribes* cubic foot volume per acre) x (Total *Ribes*/total plots sampled), ranged from 0 to 1,041. Three stands with natural *Ribes* population densities (no eradication history) had *Ribes* importance values of 1,041, 211, and 20. Even with relatively high *Ribes* values, the infection rates (percent trees infected) were low: 5, 0, and 6 percent, respectively. The remaining noneradicated stands had values of 7, 1, and 0.04, and five had values of 0.00.

In another survey of Yellowstone (Berg and others 1975), infection was closely related to elevation (table 5). Of 325,641 trees (whitebark and limber pines combined) inspected over an area of 2,246,000 acres, 959 trees were infected.

The general conclusion drawn from these surveys was that the Yellowstone environment may be poorly suited to blister rust infection. It is a cool, dry climate which, according to R. G. Krebill (1971) is only marginally suitable for blister rust teliospore germination.

In western white pine stands where this disease is devastating, individuals that are not infected stand out like a green thumb. In 1950, a program was started with the aim of determining whether this apparent resistance in western white pine was genetic or if somehow these trees were escapees—even though they were surrounded by trees that had, at times, thousands of cankers. The trees turned out to be genetically resistant. A breeding program was started with the purpose of producing new varieties of western white pine resistant to blister rust. Within the research work surrounding this program, one of the studies had the specific objectives of (1) comparing the resistance level of western white pine with other North American white pines and Eurasian white pines and (2) comparing the kinds of resistance that were observed in western white pine to those of the other pines cited above.

Table 2—Number of *Ribes* bushes eradicated in eastern Washington, Idaho, Montana, and Wyoming between 1923 and 1965

Area	Years of eradication	Number of *Ribes* bushes
Total area	1923-1965	468,420,720
Yellowstone National Park	1945-1965	10,222,300
Glacier National Park	1939-1965	4,630,900
Grand Teton National Park	1950-1965	181,700

Table 3—Percent infection of whitebark pine by blister rust

Stand name	Area No.	Data years	No. of trees per stand	No. of trees infected	Percent infected
90 miles N Vancouver, BC	1	1937	11	11	100
90 miles N Vancouver, BC	1	1937	21	21	100
Marmot Pass, WA	2	1937-39	26	24	92
Hyas Lake, WA	3	1937-39	9	8	89
Mt Rainier, WA	4	1951	602	331	55
Mt Rainier, WA	4	1952	297	154	52
Mt Wilson, OR	5	1937-39	17	12	71
Frog Lake, OR	6	1937-39	10	10	100
White River, OR	7	1937-39	23	88	
Salmon River, OR	8	1937-39	17	16	94
Quarles Peak, ID	9	1937-39	37	22	59
Windy Peak, ID	10	1937-39	17	12	71
York Creek, AB	11	1960	—	—	100
Glacier Park, MT	12	1948	2,585	48	2
Glacier Park, MT	12	1952	677	45	7
Glacier Park, MT	12	1968	—	—	45
Blackfoot IR, MT	13	1965	1,315	782	60
Gallatin NF, MT	14	1966	496/6	4	0-5
Gallatin NF, MT	14	1966	14/1	10	71
Gallatin NF, MT	14	1966	262/3	261	98-100
Custer NF, MT	15	1966	48/1	34	71-80
Custer NF, MT	15	1966	185/2	159	81-90
Yellowstone Nat. Park, WY	16	1966	?/7	—	0-.6
Yellowstone Nat. Park, WY	16	1975	325,641	959	0.3
Yellowstone Nat. Park, WY	16	1968	?/17	—	0-10
Yellowstone Nat. Park, WY	16	1968	?/1	—	21-30
Yellowstone Nat. Park, WY	16	1966	?/5	—	24
Shoshone NF, WY	17	1966	3,517/30	0	0
Shoshone NF, WY	17	1966	108/1	7	6
Bighorn NF, WY	18	1966	878/7	0	0
Bighorn NF, WY	18	1966	450/2	8	2
Bighorn NF, WY	18	1966	370/2	184	41-50
Bighorn NF, WY	18	1966	90/2	65	71-80
Bighorn NF, WY	18	1966	223/1	200	90
Wind River IR, WY	19	1966	50/3	0	0

See figure 1 for location of stand.

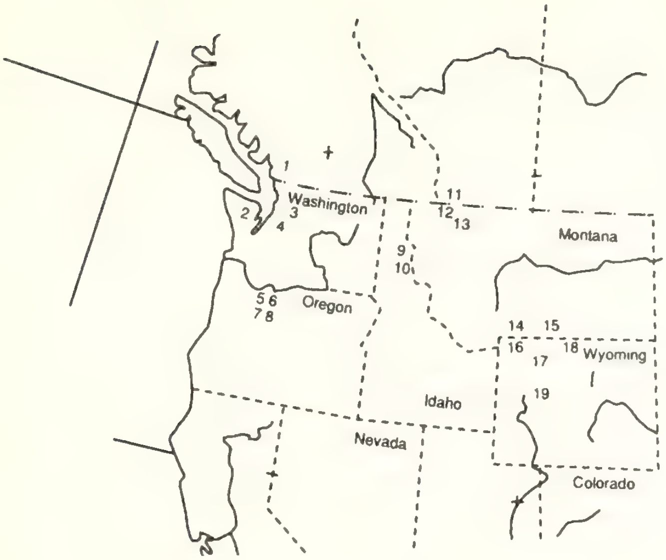

Figure 1—Location of stands listed in table 3.

Table 4—Level of infection on whitebark pine and corresponding *Ribes* populations in Yellowstone National Park

Stand number	Trees infected	*Ribes*/ acre
	Percent	*Number*
30	0.0	[1]0.0
29	.0	[1].1
22-23	.0	[1]2.0
35-37	.2	[1]3.0
10	.2	7.0
28	.3	[1]3.0
21	.6	4.0
18	1.8	4.0
9	3.3	61.0
38	3.7	105.0
14	4.6	58.0
2-4	7.5	70.0
46	23.7	91.0

[1]*Ribes* eradication 5 or more years prior to survey.

Table 5—Blister rust infection by elevation in Yellowstone National Park

Percent of all infections	Elevation
	Feet
44	Below 7,500
25	7,500-8,000
23	8,000-8,500
6	8,500-9,000
2	Above 9,000

Blister Rust Resistance in Whitebark Pine

That whitebark pine is very susceptible to blister rust was obvious to field observers; this was especially obvious where whitebark and western white pine were in a mixed stand. Several studies were completed that compared resistance among many of the white pines from throughout the world. Bingham (1972) summarized these data (table 6), and it was no surprise that whitebark pine was again rated as "most susceptible."

The research was directed toward producing new varieties of western white pine that not only had high resistance, but also had the kinds of resistance that are stable—varieties that would not be vulnerable to new races of the rust fungus. Therefore, there was interest in what mechanisms were present in the highly resistant white pines especially, where blister rust was native. The thinking was that if a certain mechanism or combination of mechanisms worked in resistant species where white pine blister rust was endemic, it would have an even better chance of surviving here—even though there were different environmental conditions involved.

Part of the collection of white pines in this study were seedlings from three phenotypic resistant whitebark pines. Although these three trees were not a very big sample, it was hoped that they would provide an idea of what was possible for whitebark pine in terms of resistance. Ultimately, 207 seedlings were generated, which was a pretty good sample. Results of the study were reported by Hoff and others (1980). They indicated that resistance in whitebark pine had increased substantially since introduction of blister rust (table 7). In the test reported, whitebark pine ranked ninth out of 16 species tested. The only North American species to rank higher was resistant collections of western white pine, a strong indication of good potential for control via resistance.

Table 6—Blister rust resistance of 14 white pines, rated as most resistant (1) to least resistant (11)

Species	Average ranking
Pinus armandii	1
P. cembra	1
P. aristata	2
P. wallichiana	2
P. koraiensis	2
P. peuce	3
P. sibirica	4
P. parviflora	5
P. strobiformis	6
P. strobus	7
P. flexilis	8
P. monticola	9
P. lambertiana	10
P. albicaulis	11

Table 7 also shows rankings of the species for six mechanisms of resistance. A brief description of the life cycle of blister rust in the pine host may be helpful. A fungus spore germinates on the surface of the leaf, enters the leaf through a stomate, and grows down the leaf, within the vascular tissue, and into the stem. After reaching the stem, it grows vertically and laterally. Fruiting of the fungus causes the most damage to the tree by physically disrupting the vascular tissues.

The first operational resistance mechanism was one that prevented the fungus from entering a leaf; it was called "no needle infection." Thirty-three percent of the seedlings of whitebark pine were in this category (33 percent of the seedlings were clean—no needle infections and no stem infections). The average over all species was 37 percent, range 1 to 96 percent. The second reaction observed was in the number of needle spots. Spots were counted and presented as number per lineal meter of needle tissue. Whitebark pine had 6.7 spots per meter; the average was 5.9 percent, range 0 to 28 percent.

Next, it was noticed that the needles with spots from some trees fell off before the fungus could reach the stem. This reaction was called "premature needle shed." After adjusting for previous resistance—the no needle infection

Table 7—Species ranked by average ranking for six mechanisms of resistance

Species	Mechanism of resistance						Rank
	NNI[1]	NSN[2]	PNS[3]	FSS[4]	BR[5]	A&C[6]	
Pinus koraiensis	2	2	4	1	1	4	2.3
P. sibirica	3	2	3	3	7	2	3.3
P. parviflora	1	1	10	9	2	1	4.0
P. cembra	4	4	2	2	6	6	4.0
P. armandii	6	6	3	5	3	11	5.7
P. monticola	9	8	2	6	4	5	5.7
P. peuce	5	2	8	6	6	8	5.8
P. wallichiana	7	5	5	3	5	14	6.5
P. albicaulis	8	10	1	4	7	13	7.2
P. strobiformis	13	9	9	8	9	3	8.5
P. morrisonicola	10	9	10	9	4	11	8.8
P. chiapensis	11	9	6	9	8	14	9.5
P. lambertiana	14	7	7	7	11	12	9.7
P. flexilis	12	11	8	7	10	10	9.7
P. ayacahuite	15	13	10	9	11	7	10.8
P. strobus	15	12	9	9	12	9	11.0

[1]NNI = no needle infection
[2]NS = needle spots per meter of secondary foliage
[3]PNS = premature needle shed
[4]FSS = fungicidal short shoot
[5]BR = bark reaction
[6]A&C = alive and cankered.

reaction—whitebark pine percentage was 38 percent. These trees had needle spots in June, 9 months after inoculation, but never developed cankers. The average was 11 percent, range 0 to 38 percent; whitebark pine rated the best of all species for this trait. The next reaction observed was caused by the interaction of the fungus and host when fungus growth down the needle reached the short shoot. This reaction seemed to produce a toxin that killed the fungus, hence it was called the "fungicidal short shoot" reaction. Again, after adjusting for the previous resistance mechanisms (no needle infection and premature needle shed), the whitebark pine occurrence rate was 7 percent. These seedlings had needle spots in June and September, 9 and 12 months after inoculation, but they also did not develop cankers. The average was 6 percent, range 0 to 90 percent. After entering the stem, other defense reactions occur that also kill the fungus. There appear to be several kinds, but they have been lumped into a single category called "bark reactions." Again, after adjusting for previous mechanisms of resistance, whitebark pine was 6 percent (seedlings never had normal cankers); the average was 7 percent, range 0 to 40 percent. The last reaction reported noted the ability of seedlings to remain alive even though they had normal cankers. This trait was called "alive and cankered" (also referred to as tolerance). Whitebark pine rated low, with only 8 percent of the seedlings alive 3 years after inoculation; the average was 21 percent, range 5 to 50 percent.

The increase in resistance of whitebark pine appears due mainly to four traits: (1) no needle infections, (2) premature needle shed, (3) fungicidal short shoot, and (4) bark reactions. Again, assuming that the three phenotypic resistant whitebark pine in this test are representative of other phenotypic whitebark pine, it seems reasonable to hope that the species is on its way to becoming resistant to blister rust.

Management of the Whitebark Pine-Blister Rust System

Management of whitebark pine in the face of blister rust is largely dependent on the relative rust hazard of the site. In some areas, such as Yellowstone National Park, where the fungus appears to be at its ecological limit, nothing needs to be done—unless global warming causes a climate change that becomes favorable to the fungus. In areas where there is high mortality, resistance appears the only option. For areas with moderate hazard, pruning and excising of cankers is a viable option.

Hagle and others (1989) produced management guidelines for blister rust control in western white pine. If one reads the document with the silvics of whitebark pine in mind, many of the recommendations can be used almost directly with only minor modification. Even though whitebark pine is more susceptible than western white pine, the cankers grow more slowly (Bedwell and Childs 1943). When high-elevation whitebark pine was compared to the main altitudinal range of western white pine, the cankers grew about half as rapidly. Therefore, in stands of whitebark pine and western white pine with equal hazard, pruning and excising of cankers should be even more effective in whitebark pine stands. Dooling (1974) evaluated the effectiveness of pruning to save relic limber pine in Yellowstone National Park. He found it to be a viable option in the localized high-use area that was treated. Only cankered branches were removed to preserve the visual quality of trees, and some of the trees required climbing for complete pruning. There were as many as 150 cankers in some trees. Acres treated were 1,367 at an average of 4 acres/person/day. The cost in 1972-73 was $20 per acre. Current costs for pruning western white pine stands range from $50 to $80; excision of cankers on pruned trees adds about $10 to $20 per acre.

Phenotypically resistant whitebark pine are fairly common; nearly every severely infected stand has a few. So there would be little problem in setting up a scheme to produce seedlings that are resistant to blister rust. Some schemes are fairly cheap; others are costly. The basic format is: (1) Collect seed from resistant individuals and either directly sow or plant seedlings in natural sites. (2) Make grafts of resistant phenotypes and plant those. (It has been noted that grafting on western white pine stock causes the whitebark pine scion to grow faster [LeRoy Johnson, personal communication]. With Swiss stone pine [*P. cembra* L.], Holzer (1975) reported that grafting on blue pine [*P. wallichiana* A. B. Jacks.] or Scotch pine [*P. sylvestris* L.] resulted not only in better growth, but in more flowers). (3) Cross breed several resistant individuals (this would assure cross pollination as compared to the above, which are probably selfs that are slow growing). (4) For both 1 and 3 above, the seedlings could be artificially inoculated with blister rust and only resistant seedlings would be planted.

A more difficult problem is to decide how far to transfer seed. We know of no data on the genetic parameters for adaptation of this species over its range. Since it appears that the evolution of this species has been greatly influenced by birds and the environment in which whitebark pine grows is uniformly severe, it would seem that adaptation would be fairly broad. So far, the known genetics of whitebark pine bear this out. Furnier and others (1987) found in an allozyme analysis that trees within clumps were more closely related than trees among clumps. This means that when a bird cached seed, it was most likely gathered from a single tree, or a cluster of trees. They found, however that there was no difference in the genetic relation among clumps, as compared to clumps collected at different sites. This means that the birds were just as likely to go long distances to cache seed as they were to cache close to the collection site. Therefore, the seed is apparently distributed over a broad area, causing good mixing of genes over that large area. Nonetheless, there probably is a photoperiod effect over the range of whitebark pine, and differences are likely in insect and disease resistance among provenances or geographic areas. A conservative recommendation, until the patterns of adaptive variation are assessed, would be to stay within a particular mountain range, for example, the Bitterroots, Cabinets, or Selkirks. Each of these areas would be treated as separate populations with resistance selections located and crossed within each. If future data show no appreciable differentiation two or more of the populations would be lumped.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from Bill Shuster)—Looking at a whitebark pine snag, can you determine if it died of blister rust?

A.—If a tree died from blister rust, there will be scars from the cankers that caused its death. Look first at the base for large basal scars and then look higher on the stem and branches for cankers.

Q. (from Wendel Hann)—If you select for resistant phenotypes, how much chance is there of also selecting for undesirable characteristics such as poor growth or survival?

A.—We have looked for those kinds of associations in western white pine, but have not seen any yet. We certainly would expect correlations of some kind, so far we can be thankful that none are obvious.

Q. (from Dick Krebill)—What percentage of whitebark pine in natural stands is likely to be resistant to blister rust? What is the chance for a new resistant population developing via natural selection without human intervention?

A.—We do not know the proportion of resistant trees. Bingham in the 1950's did a survey with western white pine and he found one tree with no cankers out of about 10,000 in the most heavily infected stands. But that is not the total picture. Trees can have cankers and still be resistant. Bob Keine ran the whitebark pine model using 5 percent resistance. At that level, there was no regeneration. He agreed to run other percentages—10 percent, 15 percent, 20 percent—until a regeneration effect is evident. He will put that in his paper in the question section.

Q. (from Kate Kendall)—I have estimates of severe whitebark pine mortality from blister rust in Glacier National Park. What was your information source for blister rust mortality in Glacier National Park?

A.—Toko and Dooling (1968, unpublished, in cited literature) reported a 1967 survey of a 45-year-old whitebark pine stand near Oldman Lake in Glacier Park in which 45 percent of the trees were infected. Two other surveys, one in 1947 and the other in 1951, of whitebark pines about 25 years old around Oldman Lake were reported in blister rust annual reports from 1948 and 1952 (Gynn and Chapman, in cited literature). A total of 2,585 and 677 trees were examined with 2 and 7 percent, respectively, infected. The Toko and Dooling survey was conducted by USDA Forest Service, State and Private Forestry, Pest Management personnel, and the second was conducted by Park Service personnel. These were surveys in what was referred to as the Old Man Lake Control Unit. The park was broken up into five control units designated as Park Headquarters, Lake McDonald, East Glacier, Two Medicine, and Oldman Lake. Oldman Lake was the only unit that had whitebark pine in the survey sample. The others had limber and western white pines. These are the only data for Glacier Park that we were able to locate. On the basis of your and other people's impressions of the situation, a current resurvey is needed.

Q. (from Anonymous)—Blister rust seems to be more common in areas of greater multiple use (grazing, lumbering) and lower in protected areas (National Parks). Could human activities be partly responsible for the spread of the disease?

A.—Blister rust mortality is high in Rainier National Park and Garibaldi National Park in Canada, and it is probably high in Glacier National Park (although we do not have survey records to show this).

However, once the fungus is in an area, intensification is local and depends mostly on the local climate, white pine populations, and *Ribes* populations. *Ribes* are seral species—early invaders of disturbed sites. They accomplish this, not by having wind transported seeds, but by having very tough seed coats and tremendous capacity for dormancy (200 or more years). This means that they can wait in a dormant condition for the next suitable disturbance. In natural forests, this disturbance would normally have been fire. Stirring or burning the duff in which *Ribes* seeds are stored stimulates germination. Human activity can greatly increase populations of *Ribes* in and near whitebark pine stands, thus influencing disease development.

HISTORICAL USES OF WHITEBARK PINE

B. John Losensky

ABSTRACT

The historical use of whitebark pine for lumber and other products is reviewed. While whitebark pine exhibits favorable wood qualities, its size and location generally precluded active management and past use was more incidental or one of convenience. This paper focuses on the Butte/Anaconda area of Montana. Records of historical use on private and public ownerships are limited and incomplete; however, the best documentation was in conjunction with mining and ore reduction activity. Present-day use continues to be incidental, with limited attention directed at management of the species. Recent harvest records are presented for Federal ownership.

INTRODUCTION

Eastern white pine, a distant cousin of whitebark pine, was eagerly sought and reserved for masts for the Royal Navy by the British during colonial days (Dana 1956). The resulting friction between the colonies and British authorities helped spark the War of Independence and the establishment of the United States of America. Whitebark pine has no such claim to fame. Descriptions of the tree often refer to it as a high-elevation tree of no commercial value (Elias 1987). Its wood is not preferred for any special uses, and in most cases the tree would have been overlooked except for a quirk of fate that placed some of the best-developed stands in the same neighborhood as major deposits of gold, silver, and copper. Thus the past use of whitebark pine is the result of its proximity to a wood market rather than an interest in its wood properties. As can be seen in table 1, whitebark pine has better wood properties than its associates Engelmann spruce and subalpine fir. Its general form, small size, and isolated location normally preclude its use, however.

LOCATION

Whitebark pine is common at higher elevations on warm aspects and ridgetops and is less abundant on sheltered north-facing slopes. It can be found in the British Columbia coastal mountains, the Olympic Mountains, and on the western slope of the Cascades in Washington and northern Oregon, but is more prominent in the Cascades of southern Oregon and northern California. In these locations the tree is generally of poor form and confined to the high ridgelines. In the Rocky Mountains it is a scattered tree, but it becomes a major component in Montana and central Idaho and parts of Alberta, Canada. Here it may form stands of relatively tall, straight trees particularly on moist, north slopes. It is abundant in western Wyoming and may develop good form there also (Arno and Hoff 1989; Day 1967).

Table 2 shows the percent of whitebark pine in the various drainages in the Deerlodge National Forest (USDA n.d.) as compiled from cruises made at the turn of the century. While logging had occurred on much of the area before the cruises were conducted, they do provide an estimate of the amount of whitebark pine present in the original stands.

A cruise conducted in the 1920's as part of a land exchange proposal north of Anaconda indicated that 15 percent of the volume was whitebark pine (USDA 1932). The major portion of this part of the exchange was in Lost Creek; minor amounts were in Antelope and Modesty

Table 1—Wood properties of whitebark pine and associated species (Forbes 1956; Hall and Maxwell 1911; Hazen (n.d.); Keenan 1970)

Species	Heat value	Modulus of rupture	Specific gravity	Weight per ft³
	million btu	*psi*		*lb*
Douglas-fir	19.2	9,600	0.43	30
Lodgepole pine	18.6	9,400	.41	29
Western white pine	17.3	9,500	.38	27
Engelmann spruce	14.7	6,000	.33	23
Fir	16.6	6,300	.37	26
Whitebark pine	16.6	8,150	.42	26

Table 2—Percent of whitebark pine by drainage on the Deerlodge National Forest

Drainage	Percent of whitebark pine
Race Track Creek	5
Lost Creek	21
Foster Creek	13
Warm Spring Creek	13
Storm Lake	7
Twin Lakes	8
Barker Creek	30
Deep Creek	19
Seymour Creek	2
La Marche Creek	17
Fishtrap Creek	17
Mudd Creek	9
Forest average	6

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Creeks. The percentage of whitebark pine is similar to that found in the earlier work. Since these sources are the only known information on the extent of whitebark pine at the time of the mining development, I decided to use them recognizing that errors may be present because of past cutting activity.

HISTORICAL USE

To understand past use of whitebark pine, it is helpful to review early timber harvest policies for the public domain. Until organized lumbermen began to commercially exploit public timber, there was little concern over its use. As with mineral deposits, land, water, and grass, timber could be used by whoever claimed it. As supplies diminished around populated areas, the Federal Government attempted to pass and enforce legislation for its use. In 1849 Congress established the Department of the Interior and in 1850 the first Federal timber agents were appointed (Butcher 1967). These agents were directed to prohibit cutting of public timber. Because of the lack of money and subsequent inability to enforce the regulations, a compromise was developed in 1860 that required payment for illegally cut timber.

Through the 1870's various attempts were made to stop the illegal use of public timber with limited success. Because of extensive problems elsewhere, the Land Office generally ignored the early development of the lumber industry in Montana (Butcher 1967). During the early 1880's there was little interest in enforcing compliance and public timber was up for grabs. When President Cleveland came into office in 1885, renewed efforts to enforce Federal timber policies were attempted. With the establishment of the Forest Reserves in the 1890's and early 1900's, policies were implemented that provided for the orderly harvest of the timber resource. In time, depredations on the public lands were finally brought under control.

Pre-1860 Period

Prior to the arrival of European man, seed of whitebark pine was used principally as a food source by Native Americans. With the California gold rush, miners may have had an opportunity to utilize whitebark pine for firewood or other uses associated with mining activity; however, because it grew only on high ridges, and early mining activities were concentrated in the major stream bottoms, other woods would have been more commonly used. No references could be found that indicated other than minor isolated use of the tree in California. Placer mining progressed to Idaho and Montana in the 1850's and 1860's. As occurred in California, most of the first discoveries were placer gold deposits at lower elevations. Towns such as Idaho City, Pierce, and Orofino in Idaho and Bannack, Virginia City, and Helena in Montana attracted thousands to the new fields (Fisher and Holmes 1968). Wood for these early operations was obtained from low-elevation forests and had limited impact on whitebark pine.

1864-1882 Period

Along with the placer mines came the discovery of significant lode claims. In Montana and Idaho many of these hardrock mines were found at upper elevations in close proximity to stands of whitebark pine. As the placer mines gave way to hardrock mines, which required milling, a new era was introduced into the territory. Hardrock mines required substantial amounts of wood for mine supports, railroad tracks, mine buildings, mills for ore reduction, huge amounts for fueling steam engines used in the mines and the mills, and wood for use in ore reduction and the refining process (USDA 1932). In addition, hardrock mining and reduction required a large permanent labor pool; these workers needed houses and wood for heat. These requirements were met by the forest resources of the surrounding area, mostly from the public domain. Because the timber stands surrounding the mines contained whitebark pine, it was natural that it was utilized along with other species.

Butte-Anaconda Area

The development of the Butte-Anaconda area was destined to play a major role in the use of whitebark pine. Not only were major mineral deposits present, but whitebark pine was common in the higher elevation stands as shown in table 2. These trees were also of good form when compared to the normal whitebark pine stands.

In 1864 the Butte area was important for its placer gold activity centered around the original town of Silver Bow (Freeman 1900). By 1866 most of the placer activity was over, and by 1868 the gravel beds had played out. Silver ore had been discovered soon after the discovery of the placer gold, and attempts were made to mill the ore in 1867. These early attempts failed often because of a lack of knowledge in milling procedures (Freeman 1900). With these failures many of the people left for other camps. This 4-year period probably resulted in a minor impact on the timber resource near Butte. William Clark, one of the "Copper Kings," acquired four mines in Butte in 1872 and the Dexter Mill in the latter part of the 1870's (Malone 1983). Continued efforts were made between 1869 and 1874 to use the quartz ores in the Butte area but with little success. In 1875 a revival of interest occurred in the quartz claims in the Butte area when smelters were developed capable of effectively milling the ore (Freeman 1900). Clark built the Colorado Smelting and Mining Company operation in 1878 to process silver ore (Malone 1983).

Since there was no railroad into Montana, all the fuel for these operations plus lumber needed for construction came from local sources. This demand was met by the forests in the Flint Creek Valley and the area immediately adjacent to Butte, Philipsburg, and Argenta. By 1879 it is estimated that 42 mills were cutting 6,000 thousand board feet (mbf) of lumber annually in Montana to meet development needs (Butcher 1967). By 1880, 3,000 people were living in Butte and the first railroad from

Utah reached the area. This event played a significant role in the expansion of the mining industry as ores or refined metals could be sent to market much cheaper and quicker (Freeman 1900).

Around 1875 "heap roasting" of ores was begun. Large lumps of almost pure sulfide ore were intermixed with layers of logs. The size of the heaps could be up to a city block long, as wide as a city street, and as high as a man (Deer Lodge County History Group 1975; Macmillan 1973). Using these estimated sizes and assuming about one third of the stack was wood, about 200 cords went into each pile. These stacks burned 2 to 3 weeks, the ore was recovered, and a new stack built. Many of these stacks would be burning at the same time resulting in a tremendous amount of cordwood used each year for this one process (Macmillan 1973). Evidence indicating the amount of timber harvested around Butte during this period is limited. But based on stand ages near Butte, much of the available timber was removed by 1885 (Joy 1989). Whitebark pine probably made up less than 2 or 3 percent of the total volume.

Marcus Daly arrived in Butte in the 1870's and in 1882 acquired an interest in the Anaconda Mine, which eventually set the stage for the development of the mill at Anaconda and major exploitation of the timber resource of Montana. Wood was the principal fuel with minor amounts of coal used where locally available. Most of the timber lands were still in the public domain, although the Northern Pacific had acquired over 1,500,000 acres for constructing a railroad through Montana (Butcher 1967). Since there was no control of cutting on the public domain, no records were kept on the amount of timber harvested. Wood cutters continued to cut what was available, moving to the higher elevations and more distant sites as local sources were depleted. A story from a Mineral County paper quoted by Davis gives a good description of the period:

> The source of heat and power in those days was mainly dependent upon the efforts of the humble woodchopper, supplemented in a small measure by costly coke shipped from the Pennsylvania coal fields. But cordwood was the main and most dependable resource. The chopper appeared in thousands and he did this job so well that the hills and mountains surrounding Butte for a radius of many miles were completely stripped of their forest growth during the years preceding the utilization of coal and hydro-electric power. Everything that would burn was cut and fed into the mouths of the boilers and smelting furnaces and much of the natural beauty of hill and mountain was changed into desolation. . ..
>
> Cordwood was a staple product and poured into Butte and Anaconda in thousands of cords daily by wagons, sleighs, pack trains, and flumes, and went up in smoke from mine hoists, smelters, "heap" roasting of ores and stampmills, to say nothing of the baseburner and kitchen stove, for wood was the only resource in which to keep the "home fires" burning (Davis 1963).

While the total use of whitebark pine may have been limited during this period, use of the forests adjacent to Butte set the stage for the exploitation of whitebark pine in future years.

Butte-Anaconda Area, 1883-1896

A major change and expansion in smelting operations was under way. Silver ore gave way to copper and the mill at Anaconda was established (Anaconda Copper Mining Co. 1909). McCune and Caplice were given a contract to supply the mill at Anaconda with 300,000 cords of firewood at the rate of 75,000 cords per year (Deer Lodge County History Group 1975; Kelly 1983). Flumes were constructed in Mill and Willow Creeks to bring the wood to the mill (figs. 1 and 2). At first mules with pack saddles were used to bring the cordwood to the flume (fig. 3). Later a narrow-gauge railroad was built into the woods with a donkey engine and long cable used to pull the cars loaded with wood to the loading platforms at the flume (Kelly 1983) (fig. 4).

It is estimated that about 718,868 cords were removed from present-day National Forest lands during this period, or about 194,000 mbf (Kelly 1983; Newell 1980). The

Figure 1—Flume in French Gulch 1906.

Figure 2—End of flume in Mill Creek near Anaconda, MT, 1906.

Figure 3—Getting wood for the Colorado Smelter, Butte, MT.

Figure 4—Tram landing 1908.

majority of this volume was lodgepole pine, but based on cruises cited in table 2, an estimated 12,000 mbf of whitebark pine may have been cut. Since much of the volume was for firewood or stulls for the mines, tree size was not important and if whitebark pine was present, it probably was taken (Kelly 1983; USDA n.d.). In 1885 there were 300 mines, nine stamp mills to crush the quartz ores, and as many as seven copper smelters operating in and around the city of Butte in addition to the works at Anaconda (Macmillan 1973). All of these operations required wood for fuel. In 1883 the mill at Anaconda alone used about 200 cords per day. By 1891 this had increased to 360 cords per day. An upgrading of the mill increased use to 700 cords per day in the fall of 1891. This rate continued through 1892. Lumber requirements for the same period were 40,000 mbf in 1888 and 100,000 mbf for both 1891 and 1892.

The mills at Butte continued to process ore using heap roasting up until about 1894 when it was outlawed by the town. A report from 1890 indicated that about 25,000 tons of ore were constantly in the process of open-air roasting (Macmillan 1973). It was becoming necessary to go elsewhere to find lumber as cutting in the Butte area had depleted much of that resource. During this period the Northern Pacific Railroad was being constructed through Montana, and it also required large amounts of wood. To meet these needs and those of the Butte-Anaconda area, the Montana Improvement Company was formed in 1882 (Butcher 1967). The first mill was established at Bonner with logs coming from the Blackfoot drainage.

In 1884 cutting began in the Flathead Indian Reservation. Much of this volume was for the railroad construction, but portions found its way into the lumber market or the mines. In 1888 the lumber mills in Montana produced 150,000 mbf, a large portion of which went to the Butte-Anaconda operations (Butcher 1967).

1897-1905 Period

While placer mining began early in Idaho, hardrock mining in the whitebark pine environment was delayed until the 1890's. The Spring Creek area on the present-day Salmon National Forest was developed at this time, and a stamp mill was constructed on site. It is unclear how long this mine was active, but use extended into the early 1900's (Jacobsen 1989; Umpleby 1913). In several areas along the Continental Divide old wood ricks remain that had been cut for firewood for these mills. Many of these ricks contain large amounts of whitebark pine (Hamilton 1989), but no estimates of volume could be made.

Butte-Anaconda Area

There are few references to timber use during this period in the studies reviewed. If harvest continued at the same rate as in the previous period, approximately 500,000 cords may have been harvested in the immediate area. This may represent 8,000 mbf of whitebark pine. The new smelter was completed at Anaconda, which greatly increased the milling capacity; however, increased availability of coal may have precluded any major change in firewood needs (Deer Lodge County History Group 1975; Kelly 1983).

The use of electricity, which would eventually replace wood for fuel in many applications, was also increasing (Johnson 1988; Quivik 1988). The Alice Mine became the first mine in Butte to use electric lights in 1881, and by 1900 Butte mines used electricity for surface tramming. As early as 1890 a small dam on Georgetown Lake was supplying electricity for the mines at Granite, but technology to transmit the amounts of electricity required for the large mills was not available (Johnson 1988; Quivik 1988; Sorte 1960). Daly installed an onsite generation plant using coal at Anaconda about 1890 (Quivik 1988). Coal needs were obtained from the towns of Storrs and Aldridge in the Bozeman area (Chadwick 1973). By the 1900's steam generation plants were running in Butte and a hydroelectric plant had been installed on the Big Hole River near Divide. Additionally, power was being

produced at Canyon Ferry on the Missouri River and brought to Butte on relatively low-voltage lines. In 1905 Anaconda Company acquired the plant at Ennis and enlarged it for additional electricity production (Johnson 1988).

Butte-Anaconda Area, 1906-1915

Major changes in the operation of the mills and ownership and control of the timber resource occurred during this period. In 1906 all smelting operations in Butte were moved to Great Falls with the exception of the Butte Reduction Works operated by William Clark. He continued the business until 1910 when he finally sold his operations to Anaconda (Malone 1983). Wood for the Great Falls plant was brought from Kalispell as well as the Missoula area and was obtained from low-elevation stands of larch, Douglas-fir, and ponderosa pine.

In 1905 the Hell Gate Forest Reserve was established and in 1906 the Big Hole Reserve. The Deerlodge National Forest was formed from portions of these reserves in 1908. Starting in 1906, records are available on volume removed from these reserves. Unfortunately, species are not identified. One of the first sales was to W. R. Allen for 100,000 mbf in the French Gulch drainage (USDA n.d.). He built an extension to the McCune flume that crossed the Continental Divide into the Bighole drainage. The flume crossed the divide at about 7,000 ft elevation, which is generally near the lower limits of whitebark pine (Joy 1989). The flume covered about 18 miles, and had 29 trestles, the highest of which was 72 ft and spanned 775 ft (fig. 5). Most of the timber cut was for firewood and stulls for the mine (fig. 6). Cutting occurred throughout the year with the floating season from May to November (Newell 1980). Many problems occurred with this sale, often the result of Forest Service inexperience in administration of a sale of this size. At first the logger was allowed to select what he wanted. In late 1906 cutting rules were developed with clearcuts 150 ft wide interspersed with 75-ft leave strips. Later this design was divided into 75-ft^2 alternate blocks. Windfall was a major problem with this design. In 1909 a system was established using strips 100 to 150 ft wide. This approach resulted in many small unmerchantable trees being left. In 1910 the rule was changed to clearcutting in overmature stands and thinning in immature stands. Allen got a new contract for an additional 100,000 mbf, and cutting continued until 1917 when the contract expired. At that time operations were moved to lower elevations in the Flint Creek drainage where whitebark pine was less frequent (Newell 1980).

Cutting continued in other areas around the Butte-Anaconda area. An estimated 8,600 mbf of whitebark pine was harvested. This estimate was developed by using the percent of whitebark pine present by drainage (table 2) for sales over 7,000 ft elevation. This period marked the end of heavy cutting in the Butte-Anaconda area. The demand for firewood dropped significantly after 1912 as electrification was implemented in the mills. Between 1908 and 1910 a new dam was built at Rainbow Falls near Great Falls and a 100-kW line was built to the

Figure 5—Trestle on French Gulch Flume 1906.

Figure 6—Fuelwood and stull cutting, French Gulch 1908.

Butte-Anaconda area. This was one of the first long-distance transmissions of high voltage and permitted the mills to turn to more electrification (Quivik 1988). Up to this point all hoist operations, which represented a major energy demand at the mines, were supplied by steam. These were now converted to electricity.

1916-1940 Period

During the early 1930's "tie hackers" for the Chicago, North Western, and Burlington Northern Railroads cut ties in the Dunoir area west of Dubois, WY. Whitebark pine is found on these sites mixed with lodgepole pine. It has a good form, and it was harvested along with the other species present. No estimates of this use are available, however (Houston 1989).

Table 3—Estimated whitebark pine use in the Butte-Anaconda area between 1860 and 1940

Time period	Estimated whitebark pine harvest
	(thousand board feet)
1860-1882	3,000
1883-1896	12,000
1897-1905	8,000
1906-1910	3,200
1911-1915	11,400
1916-1920	800
1921-1925	180
1926-1930	180
1931-1935	60
1936-1940	10
Total	38,830

Butte-Anaconda Area

Between 1914 and 1923 the annual requirement for wood products in the Butte-Anaconda market was 400,000 stulls, 55,000 converter poles, 130,000 lagging poles, and 3,000 cords of firewood for area home use (USDA 1932). Volumes continued to decline with most of the harvest in latter years going for home fuel.

The area north of Anaconda was described as having most of the accessible material removed by 1924. The Anaconda Copper Mining Company's needs came chiefly from the Big Blackfoot Drainage (USDA 1932). Of the 35,000 acres evaluated by the proposed exchange, 28,000 were listed as logged and 3,800 acres burned. Much of the area was clearcut and most of the marketable-sized material was taken. By 1919 coal was the principal fuel used in the smelting process (Anaconda Copper Mining Co. 1919). Natural gas came to the area in 1932 and further reduced dependency on wood and coal (Kelly 1983).

Summary of Whitebark Pine Use

It is evident that significant use was made of whitebark pine between 1860 and 1940. A major portion of the volume came from the public domain during a period of laissez-faire attitude in the country. No attempts were made to record use, and figures available represent information that was collected by government agents years after the fact. Table 3 presents an estimate of use of whitebark pine between 1860 and 1940 for the Butte-Anaconda area; it does not include other parts of Montana. These areas may account for an additional 500 mbf.

As a check of these figures, a rough survey of cutover lands in the Butte-Anaconda area was conducted. Using volumes presented in the Deerlodge National Forest Plan (USDA 1987), an estimated 100,000 mbf of whitebark pine may have been utilized. These values suggest that total use may be somewhere between 40,000 mbf and 100,000 mbf. Based on the fragmentary information for the ACM Company during the period from 1882 to 1925, it is estimated that 4.7 billion board feet of wood was used by their operation alone. In addition some 50,000 mbf was used for home heating. Before 1906 an unestimated amount was used by the other mining operations not controlled by Anaconda. While these figures are only rough estimates, they provide an expression of the magnitude of timber activity found around the Butte-Anaconda area and the role whitebark pine played in that use.

RECENT USE

Presently, the role of whitebark pine in timber harvest is insignificant. Harvest activity continues to occur in this type in Montana, Idaho, and Wyoming. Most whitebark pine harvest is in conjunction with spruce or subalpine fir with which it is growing. Cutting during the past 20 years has occurred in northwestern Wyoming in the Bridger-Teton National Forest, but it has been incidental to regular timber harvest and amounts are included with other species. The extent of this cutting could not be determined. A similar condition was found in Idaho where cutting in the type has occurred in the Salmon and possibly the Payette National Forests. Significant acres of the type were killed by mountain pine beetle in the 1930's and 40's in Montana and Idaho. Where accessible, much of this material is currently being used for firewood or house logs. Again no records have been kept to determine the extent of this activity (Jacobsen 1989). Regeneration efforts are geared to replacing the stands with spruce or lodgepole pine and whitebark pine regenerates through natural regeneration.

An estimated 900 acres of whitebark pine type have been harvested in the Northern Region. Table 4 provides a breakdown by forest, which indicates that most harvest has occurred in the Gallatin and Deerlodge National Forests. Much of the type has been allocated to noncommodity uses in recent National Forest planning efforts. Similar information is not available for the Intermountain Region as it is lumped in with other types. California and the Pacific Northwest Regions have no reported use of the type. Indications are that the trees in these areas are of poorer form and, therefore, have been ignored in timber activity. Limited investigations were made on utilization of whitebark pine in Canada. A report by Day suggested that some large stands are found in Alberta in the Crowsnest Forest. Some of these stands contain 10 percent or more of large whitebark pine (Day 1967), which has been harvested and sold along with the lodgepole pine.

Table 4—Acres harvested in the whitebark pine type by National Forest in the Northern Region

Montana forests	Acres	Idaho forests	Acres
Bitterroot	29	Clearwater	1
Beaverhead	91	Kootenai	42
Custer	7	Nezperce	8
Deerlodge	176		
Flathead	37		
Gallatin	402		
Helena	22		
Kootenai	42		
Lolo	67		

CONCLUSIONS

While it is quite evident that significant amounts of whitebark pine have been used in the past and minor amounts are still being cut, there has never been a real interest in whitebark pine lumber or management for whitebark pine. If turn-of-the-century mining activity had been adjacent to the timber types found in the Kalispell, Missoula, or Bitterroot Valley areas, whitebark pine would probably have been ignored. Its use has been based on convenience and its association with other tree species. Use of whitebark pine will probably never reach the heights it experienced at the turn of the century and its place in the future may be that of providing food for wildlife. We still have much to learn about the tree itself.

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BERRY PRODUCTION IN THREE WHITEBARK PINE FOREST TYPES

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ABSTRACT

In the whitebark pine /whortleberry (Pinus albicaulis/ Vaccinium scoparium) *habitat type of southwestern Montana, whortleberry plants produced seven to 69 berries / m² x yr in 1974. In subalpine fir* (Abies lasiocarpa) *habitat types of northwestern Montana, huckleberry plants* (Vaccinium globulare) *may produce from 13 to 228 berries / m² x yr. While removal of competing trees increases production, thinning the understory apparently reduces berry production in direct proportion to the shrubs removed; there is no compensatory production indicative of shrub-shrub competition in fully vegetated plots. Fifty- to 100-fold variation in production among years in* Vaccinium globulare *berry production is attributed to variation in weather conditions.*

INTRODUCTION

Vaccinium species are common associates of whitebark pine (*Pinus albicaulis*). Whortleberry (*Vaccinium scoparium*) dominates the understories of relatively dry high-altitude forests in which whitebark pine is either climax (*Pinus albicaulis/Vaccinium scoparium* and *Abies lasiocarpa-Pinus albicaulis/Vaccinium scoparium* HT's) or seral (*Abies lasiocarpa/Vaccinium scoparium* HT). Lower in whitebark pine's altitudinal range, and especially on relatively moist sites near the Canadian border, one also finds huckleberry (*Vaccinium globulare*) in communities including *Abies lasiocarpa/Xerophyllum tenax-Vaccinium globulare* HT (Martin 1979). Habitat type (HT) and plant association names follow Pfister and others 1977.

Vaccinium berries are important foods of bears (black and grizzly), birds (Clark's nutcracker, Cassin's finch, flickers, ravens, and robins), small mammals (squirrels, redbacked voles, and deer mice), and humans; and their production is therefore of interest to wildlife managers. This note summarizes our observations on the variation in berry production with changes in habitat type, overstory cover, shrub cover, and year.

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METHODS

Two independent studies were conducted, one in the Madison Range of southwestern Montana near Bozeman, and the other in the Glacier National Park and Whitefish Range in northwestern Montana.

Whortleberry fruit densities in the understories of five *Pinus albicaulis/Vaccinium scoparium* forests in the Madison Range study were determined by counting the berries in m^2 quadrats placed at alternate meters along the center line of 10- by 30-m plots sampled in a study of forest productivity (Forcella 1977; Forcella and Weaver 1977). Berry density was also recorded in a clearcut ski-run between the two forest stands measured on Lone Mountain (Madison Range near Bozeman, MT). All berry counts were made during August of 1974.

Huckleberry fruit densities were measured in relatively young forests on *Abies lasiocarpa-Pinus albicaulis/ Vaccinium scoparium* and *Abies lasiocarpa/Xerophyllum tenax-Vaccinium globulare* habitat types in the Rocky Mountains of Glacier National Park and in the adjacent Whitefish Range. Whitebark comprised relatively low percentages (4 to 40 percent) of the forest canopies, both because whitebark pine is being eliminated from the stands by white pine blister rust (Hoff and Hagle, this proceedings; Kendall and Arno, this proceedings) and because whitebark is never fully dominant in the relatively moist climate of the area (Arno and Weaver, this proceedings). Annual counts (1983-88) were made in seven forests; 20- by 20-cm plots were placed at 50 points located by pacing from permanent stakes along specified compass lines. While *Vaccinium scoparium* was present in some of these plots, its berries were never counted.

AVERAGE BERRY PRODUCTION IN WHITEBARK PINE STANDS

Average whortleberry production ranged from seven to 69 berries/m² in five closed *Pinus albicaulis/Vaccinium scoparium* stands observed in southwestern Montana during the summer of 1974 (table 1). Because July-August precipitation in 1974 was 132 percent of normal and precipitation in the preceding August was 119 percent of normal (USDC 1973-1989), these yields are probably average or above average. The average whortleberry weighed (dry) 0.0075 g.

During the 1983-88 period, huckleberry production averaged 45 to 228 berries/m² in three *Abies lasiocarpa-Pinus albicaulis/Vaccinium scoparium* stands and 13 to

Table 1—*Vaccinium* berry production (berries/m²) in three habitat types

Environmental type (HT)[1]	Location[2]		Year	Arboreal cover	Wortleberry Cover	Wortleberry Berries	Huckleberry Cover	Huckleberry Berries
				Percent	*Percent*	*Per m²*	*Percent*	*Per m²*
PIAL/VASC[3]	Madison	1LM	1974	73	42 ± 3	68 ± 9	none	present
	Madison	1-2	1974	0	48 ± 4	372 ± 47	_	_
	Madison	2LM	1974	97	44 ± 4	52 ± 9	_	_
	Gravelly	10MM	1974	52	31 ± 3	69 ± 10	_	_
	Elkhorn	11	1974	40	21 ± 2	7 ± 2	_	_
	Tobacco Rt	14	1974	56	50 ± 3	15 ± 4	_	_
ABLA-PIAL/VASC[3]	Lewis	2DF	1983-1988	4	0	not	60	135 ± 65
	Lewis	3MB	1983-1988	22	26	counted	30	45 ± 15
	Apgar	6HM	1983-1988	0	30	_	35	228 ± 141
ABLA/XETE-VAGL[4]	Whitefish	1MO	1983-1988	24	35	_	50	34 ± 7
	Whitefish	2MO	1983-1988	44	60	_	35	13 ± 5
	Lewis	1MB	1983-1988	16	35	_	52	64 ± 14
	Lewis	1TM	1983-1988	42	0	_	70	33 ± 7

[1]Habitat types are *Pinus albicaulis/ Vaccinium scoparium*, *Abies lasiocarpa-Pinus albicaulis/ Vaccinium scoparium*, and *Abies lasiocarpa/ Xerophyllum tenax-Vaccinium globulare* (Pfister and others 1977).
[2]Locations are given by mountain range and site number. PIAL/VASC sites are described in more detail by Forcella 1977.
[3]*Vaccinium scoparium* (VASC) standard errors represent quadrat to quadrat variance, $n = 15$.
[4]*Vaccinium globulare* (VAGL) standard errors represent year to year variance, $n = 50$.

64 berries/m² in four *Abies lasiocarpa/Xerophyllum tenax-Vaccinium globulare* stands in northwestern Montana. Huckleberry weights (dry) range from 0.02 to 0.11 g and average 0.06 g (Stark 1990).

OVERSTORY-UNDERSTORY COMPETITION

Removal of the whitebark canopy in an area between stands 1LM and 2LM resulted in a sixfold increase in whortleberry fruit production (table 1). Regression of huckleberry production against overstory cover indicates exponential decreases in berry production with increases in overstory cover; the equation [berries/m² = 214 *e* (– 0.075 canopy cover)] explains 96 percent of the variance in the berry production data ($r^2 = 0.96$) and has a probability of 0.001. Removal of the tree canopy also increased huckleberry production in nonwhitebark forests (Minore 1972; Zager and others 1980).

The inhibition of berry production by tree canopies is often attributed to lack of light energy (Dahlgreen 1984; Martin 1983). Other hypotheses seem equally good. Since the failure of tree seedlings in closed forests is sometimes due to lack of water or nutrients rather than lack of light (Watt and Fraser 1933; Weaver 1974), and since the failure of seedlings in whitebark forests appears to be more likely due to edaphic than light factors (Weaver and others, this proceedings), berry production might also be limited by an edaphic factor. An additional possibility is that berry production might decrease with increases in canopy cover if lack of light inhibited pollinators or promoted flower- or fruit-attacking fungi.

COMPETITION AMONG SHRUBS

If berry plants compete, one expects the production per unit area covered to fall with increases in percent of shrub cover. The hypothesis of strong within-species competition among whortleberry plants is negated by the linear rise in berry production with increases in *Vaccinium* cover both in closed stands (berries/m² = 0.65 cover + 18.75, $r^2 = 0.56$) and in logged stands (berries/m² = 9.85 cover – 102, $r^2 = 0.66$, $p = 0.0$). In huckleberry stands neither we nor Martin (1983) found any correlation between shrub cover and berry production.

WEATHER AFFECTS HUCKLEBERRY PRODUCTION

Huckleberry fruit production varied considerably among years with notable lows across most stands in 1984 and 1987 (table 2). Year-to-year variance surely depends on a succession of weather-condition effects on flower initiation, pollination, winter kill, plant carbohydrate stores, and photosynthesis during the berry-filling period. The poor production observed across all stands in 1984 and 1987 suggests a common meteorological cause. We (1) hypothesize that water was the factor most likely responsible, (2) eliminate rainfall in the bearing season as a factor because, while 1984 was dry, 1987 was wet, and (3) speculate that the failed crops were due to drought during the flower bud initiation season, because the Augusts preceding both 1984 and 1987 were very dry (table 3).

Table 2—Annual variation in huckleberry berry production (in percent of maximum berry count/m²)

Site	Max/m²	1983	1984	1985	1986	1987	1988
2DF	410	60	15	11	100	0	11
3MB	95	48	19	89	34	0	100
6HM	512	100	18	99	29	0	21
1MO	58	86	21	48	45	47	100
2MO	29	86	3	31	14	31	100
1MB	95	77	57	100	88	3	771
1TM	51	86	10	94	100	55	47
Berry index[1]		17	36	19	21	36	20

[1]Berry yields were recorded in seven stands for 6 years. Yields were ranked across years by giving the high production a 1, the low production a 6. Ranks were summed across stands to index the productivity of each year. Productivities were similar in all years except 1984 and 1987 when high scores indicate poor crops.

Table 3—Precipitation (inches) in West Glacier, MT. Months with less then half of normal precipitation are asterisked

Month	Year: Berry Index[1]:	1982	1983 17	1984 36	1985 19	1986 21	1987 36	1988 20	Normal
May		1.40	0.96*	3.54	3.00	2.55	1.96	3.27	2.51
June		2.48	4.41	2.83	1.77	3.44	2.05	1.58*	3.42
July		2.58	4.70	.42*	.09*	3.02	3.32	1.56	1.44
August		.89	.52*	.73*	2.08	.54*	2.20	.36*	1.49
September		2.12	1.43	3.61	4.83	3.49	.33*	1.83	2.25

[1]High berry yield indices from table 2 indicate low yields in 1984 and 1987. While one summer was dry (1984) and the other one was wet (1987), both were preceded by dry Augusts.

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USE AND IMPACT OF DOMESTIC LIVESTOCK IN WHITEBARK PINE FORESTS

E. Earl Willard

ABSTRACT

The whitebark pine (Pinus albicaulis) *ecosystem has historically been important as summer range for livestock. These ranges supply nutritious, green forage to supplement the often-dry summer ranges of lower elevations. Many areas were grazed by huge herds in the late 1800's and early 1900's. These herds have been greatly reduced due to recognition of the unacceptable levels of disturbance to the soil and vegetation, leading to overall range improvement. This paper summarizes the impact of livestock grazing in the whitebark pine ecosystem, including a history of grazing, disturbance of soils and plant communities, changes in livestock numbers and grazing management, and a view of the future.*

INTRODUCTION

Whitebark pine (*Pinus albicaulis*) ranges occur in a cold, windy, snowy, and generally moist climatic zone at timberline (Arno and Hoff 1989). Stands occur in a mosaic of subalpine parklands and alpine meadows, often remote and on steep, rugged terrain.

A combination of high precipitation, unstable soils, fairly steep slopes, and a short growing season with extreme weather variations makes proper livestock grazing very difficult on such ranges (Mueggler 1962). Blizzard conditions commonly occur in timberline types in all months except July and August (Pfister and others 1977). Since the snow is slow to melt in the spring, the soil is slow in warming and plant growth is delayed; the growing season is short (Thilenius 1975). Thus, livestock use the whitebark pine zone as summer range.

One problem with maintaining livestock on high-elevation ranges too late into the season (mid to late September) is the chance of heavy snowfall. Early fall snowstorms are disadvantageous in two ways: (1) the obvious danger of high losses of animals, and (2) the danger of heavy trampling damage to the soil where the soil has been moistened by snow, but where it is not yet solidly frozen (Thilenius 1975).

Some sites such as drainage bottoms, wet meadows, and grassy slopes are preferred by livestock, while forested sites and steep slopes are less preferred (Willard and others 1983). Water is often located in drainage bottoms and unevenly distributed. When cattle water in the bottoms, they tend to spend more time on the lower slope as the slope becomes steeper. For example, Mueggler (1965) found that on a 10 percent slope, 75 percent of cattle use is likely to be within 810 yd of the foot of the slope; on a 60 percent slope, 75 percent of cattle use will probably occur within 35 yd of the bottom. Thus, livestock grazing distribution is usually uneven on such ranges.

Jardine and Anderson (1919) reported that each class of livestock uses the high-mountain ranges differently. Cattle prefer open grassy parks and meadows close to water and shade. Horses prefer high, open grass ridges; compared with cattle they will travel longer distances to water. Sheep will penetrate and utilize small areas of fallen timber; they can easily utilize areas that can be ridden through on horseback, and if quietly handled they will use areas that a horse cannot get through. Horses will use grass range not well suited to sheep and too far from water or too rough for full use by cattle.

Sheep are the principal livestock now using the subalpine zone, since most breeds of cattle are poorly adapted to the colder, windy climate (Thilenius 1975). Horse use is significant in wilderness areas, mostly by recreationists' and government administrative stock.

Livestock forage in the whitebark pine ecosystem varies considerably, depending on the local climate, associated vegetation types, and past grazing. Some dry-site whitebark pine stands in semiarid regions have open, grassy understories, but undergrowth is sparse in Sierra Nevada stands (Arno and Hoff 1989). Common juniper (*Juniperus communis*), practically worthless as livestock forage, is a major understory plant in Alberta stands (Baig 1972). Steele and others (1981) stated that forage production may sustain light grazing, but in many areas grazing abuse has decimated the forage and exposed the soil; vegetation recovers slowly and, in some areas, soil loss may preclude complete restoration.

Pfister and others (1977) reported that the major understory species in Montana of value to livestock include *Calamagrostis canadensis, C. rubescens, Carex geyeri*, and *Xerophyllum tenax*. Forage production is low in these stands. However, forb and grass growth may be luxuriant

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in certain timberline areas, particularly those east of the Continental Divide on better soils. These ranges are presently grazed very little in Montana (Willard and others 1983).

Steele and others (1981) reported that *Arnica cordifolia* is often the dominant forb in the undergrowth in Idaho; livestock seldom find much forage in the understory but may use these sites for bedding and shelter. Whitebark pine stands farthest from areas of heavy grazing may have an undergrowth dominated by *Festuca idahoensis* or *Stipa occidentalis*. Understory species vary considerably and range from *Festuca idahoensis* on dry, exposed sites to *Carex geyeri* and *Vaccinium scoparium* on more mesic sites.

Franklin and Dyrness (1973) reported that on associated alpine meadows in Oregon and Washington, the major community of importance to livestock is the *Festuca viridula/Lupinus latifolius* community. It is snow-free for a period of 3-4 months. Other communities are of very limited value to livestock.

Mueggler (1962) stated that subalpine herblands that are natural openings on high-elevation slopes and ridges in northern Idaho form only a small part of the range area, yet furnish an important part of the summer forage. Such areas in good condition produce abundant grasses and forbs, but they are very sensitive to grazing abuse.

EARLY GRAZING—THE WESTERN COMMONS

Galbraith and Anderson (1971) reported that cattle were driven from Washington in 1858 to the British Columbia gold mines near Kamloops. Soon, other herds were driven to the Cariboo mining district. The preferred ranges on public lands in British Columbia became badly overgrazed before the Grazing Act was passed in 1919.

During the period of 1850 to 1890, there was rapid expansion of cattle and sheep ranching onto open range in Oregon and Washington. Sheep in great numbers were moved into eastern Oregon and across the Columbia River into Washington beginning in 1892. Sheep were far less expensive than cattle to feed and care for on the range. The market was limited, so the sheep quickly multiplied until the market eventually improved. Sheep numbers rose spectacularly from 1865 to 1901. This was the period of trail herding, when as many as 600,000 sheep were trailed from California and Oregon to stock ranges farther east (Thilenius 1975). Sheep numbers peaked in the western United States around 1910.

Livestock were first introduced into Montana in the mid 1800's. By 1880, approximately 400,000 sheep were reported in the Montana Territory. In the early 1890's, sheepmen gained a foothold on the ranges, especially in the northwestern States. In some States, especially Wyoming, Montana, and Idaho, sheepmen gradually forced the cattle interests from many of their old ranges (Barnes 1926), and many cowmen turned to raising sheep. Sheep in Montana increased to nearly 6 million by 1906.

Sheep were moved up the mountains into the subalpine/alpine zone—more or less following the snow line—for summer grazing. High mountain ridges were often a cloud of dust for most or all of the summer. Intense competition occurred between herders to be first to move their bands onto preferred mountain ranges. No sheepman chose to save forage for future use, knowing it would be sought out by another herder with a hungry band of stock. It was common practice to graze everything into the ground before the sheep were moved down the mountain in the fall. The situation was graphically described by Barnes (1926):

> Every spring the herds of sheep followed the melting snows into the high mountain meadows just as soon as the ground was uncovered. The hungry sheep fed on new plant growth, and their sharp hoofs trampled and cut up the sod until bare wastes took the place of grassy meadows and bunchgrass hillsides. From the pinnacles the owners watched with jealous eyes each other's progress into the high ranges. By day the cloud of dust that rose above the migrating herds, and by night the fires built to keep off the predatory animals, showed the advance of the rival herds.

END OF OPEN RANGE ERA

Much of the whitebark pine ecosystem is located on public lands. The first major act to control grazing on these lands was the reservation of large acreages in National Forests, which provided for grazing controls and grazing fees. The first forest reserve was established in 1891; many others were established by 1900. Grazing control on these forest reserves between 1900 and 1905 was difficult (Dana 1956). Sheep grazing was at first forbidden in all reserves outside Washington and Oregon. The policy was changed in 1901 to allow sheep in those portions of reserves where it could be shown that sheep grazing would not be detrimental.

Initially, horse and cattle grazing were regarded as less detrimental than sheep grazing, so they were subjected to little control on forest reserves. In 1900, however, permits were required for all classes of livestock. Jardine and Anderson (1919) reported that in 1907 approximately 18,500 permits were issued for the grazing of cattle and horses on the National Forests; by 1917 the number had increased to approximately 32,000. In 1907 approximately 1,250,000 head of cattle and horses were grazed, and in 1917 over 2 million were grazed.

In 1906, grazing fees were adopted on forest reserves to help bring grazing under control. These permits were issued for a specific number of animal unit months (AUM's) of grazing on a specified area. These were granted to ranchers who owned enough property to support the animals when they were not on the forest reserve. Thus, public land grazing permits were tied to individual private ranches. Excessive livestock grazing and trespass grazing within forest reserves continued to be a major problem for many years. These were slowly reduced, but the practices had become deeply entrenched.

GRAZING IMPACTS

Infiltration and Sediment Yield

Research is limited relative to hydrologic impacts of livestock grazing in the whitebark pine ecosystem. However, extensive evidence is available that shows the negative hydrologic impacts of excessive grazing in other vegetation types. Livestock influence infiltration rates and sediment production on watersheds by removing the soil's protective cover and compacting the soil. An adequate vegetative cover is generally accepted as the most important factor in maintaining adequate infiltration and preventing erosion.

Meeuwig (1971) stressed the importance of maintaining vegetation and litter cover for adequate infiltration and soil stability on rangelands in Utah, Idaho, and Montana. On a subalpine watershed in Utah, Meeuwig (1960) reported that heavy grazing reduced vegetative cover and created a serious flood source area.

Mueggler (1962) stated that many subalpine herblands in northern Idaho and northeastern Washington are seriously depleted because they have been grazed too heavily by cattle and sheep during the short summer grazing period. He indicated that forage depletion, sheet erosion, and gullying are evident in many areas. These areas now produce only a fraction of their potential forage. However, the most serious result of overgrazing was expressed as loss of the soil mantle.

Plant Community Indicators

Range condition and trend on high-elevation ranges are recognizable by certain signs or indicators that can be detected by observing the soils and vegetation on a site. These indicators not only provide an insight into changes that may have occurred during the past because of livestock grazing, but also suggest what may be expected to occur in the future if the manner of grazing is not altered (Ellison and others 1951).

Jardine and Anderson (1919) stated that overgrazing for an extended period leaves signs that are readily recognized. These signs were listed as follows: (1) the predominance of annual forbs and grasses, with a dense stand of such species and lack of variety in species; (2) the predominance of plants that have little or no value for any class of stock; (3) the presence of dead and partly dead stumps of shrubs; (4) noticeable damage to tree reproduction; and (5) erosion and bareness.

Ellison and others (1951) stated that three characteristics of high-mountain vegetation are especially important to consider in judging range condition and trend on high-elevation ranges:

1. On range in good condition, the vegetation, along with the litter it produces, effectively protects the site against soil erosion, especially since the cover tends to be greater on high-mountain range than on lowland range. Bare spots are neither naturally large nor permanent on such sites.

2. Vegetation of high-mountain sites in good condition usually supports many kinds of plants.

3. There is a dominance by perennial plant species. If annuals are present, they make up only a small part of the community. Conspicuous annuals in high-mountain vegetation indicate the range is not in good condition.

Sampson (1919) described four vegetation types or stages in plant succession on high-mountain ranges in Utah. These stages, listed in order from the most disturbed to climax, include the following: (1) early maturing annuals and weak perennials; (2) perennial herbs, chiefly forbs with some aggressive grasses and shrubs; (3) aggressive perennial grasses in abundance with perennial herbs and shrubs; and (4) deep-rooted or densely tufted perennial grasses, growing almost to the exclusion of other plants. These stages have been widely studied by numerous workers on subalpine grasslands, and the validity of this classification has been generally accepted (Pickford and Reid 1942).

The climate of alpine and subalpine rangelands is adequate for luxuriant plant growth. Thus, whenever the perennial plant cover of a site is less than normal, even though it may be adequate to prevent accelerated erosion, an unsatisfactory condition is indicated by two conditions (Reid and Pickford 1946): (1) reduced cover reflects a lower production of forage, and (2) the site becomes more xeric. A range in good to excellent condition is more mesic than one in poor to fair condition. When the climax dominant plants are lost from a dry site, the site is slower to progress to a climax condition than when it is a mesic or wet site.

Meadows at timberline in good to excellent condition support a dense sod of perennial grasses and sedges with few perennial forbs and essentially no annuals (Reid and Pickford 1946). Severely overgrazed meadows have a reduced cover of plants that is mostly annuals. Intermediate seral stages have a mixture of perennial grasses and sedges, perennial forbs, and annuals. Thus, increased range deterioration is indicated as perennial forbs and annuals increase.

Pickford and Reid (1942) also described these high-elevation communities in climax condition as dominated by grasses, with a small amount of forbs present. They indicated that as range condition declines, the perennial forbs and sagebrush increase on the site. Since the drier sites decline in range condition more readily than wetter sites (Reid and Pickford 1946), sagebrush first shows up on these dry sites and is an indicator of range deterioration.

Sheep tend to prefer forbs over grasses, thus an overgrazed sheep range would be characterized mostly by low value grasses (Ellison 1954). As overgrazing continues, the less-preferred perennial grasses decline so that unpalatable forbs and annuals predominate. Dominance by rhizomatous species represents an intermediate level of range condition (Ellison and others 1951).

Plant Species Indicators

Subalpine rangelands in eastern Oregon and Washington that support chiefly *Stipa columbiana* and forbs indicate unstable soil and vegetation conditions (Pickford and Reid 1942) caused by overgrazing. These can be used as indicators of excessive grazing on these sites.

Annuals that are indicative of overgrazing on high-elevation ranges in the Intermountain region include *Lepidium, Polygonum, Amaranthus,* and *Descurainia* (Ellison and others 1951). *Madia,* where it is a strong competitor, is considered to indicate a poorer condition than the other annuals.

Reid and Pickford (1946) described the vegetation on overgrazed sites in eastern Washington and Oregon. *Poa pratensis, Koeleria cristata, Bromus carinatus, Agropyron trachycaulum, Achillea lanulosa, Potentilla, Aster occidentalis,* and *Taraxacum officinale* are found on such sites. Dense stands of *Wyethia* are an indicator of poor condition. Annuals that are found on disturbed sites include *Polygonum douglasii, Gilia, Gayophytum,* and *Madia.*

Festuca idahoensis appears to be a major dominant species on high, open ridges. Branson and Payne (1958) found that this grass decreased with excessive sheep grazing in the Bridger Mountains of Montana. Morris (1961) considered *Festuca idahoensis* to be a decreaser in Cabin Creek and Sage Creek in southwestern Montana. Kuramoto and Bliss (1970) reported that *Festuca idahoensis* is the most important species in the mesic grass type and dry grass-forb type of the Olympic Mountains, WA; reduced abundance of this species was said to indicate regression from climax condition.

Plant species most abundant on heavily grazed sheep range include *Stipa lettermani, Agropyron trachycaulum, Achillea lanulosa, Aster,* and *Taraxacum officinale* (Ellison 1954).

Branson and Payne (1958) used exclosures to compare vegetation on protected sites to those grazed by sheep in the Bridger Mountains of Montana. They found that sheep grazing led to a decrease of *Festuca idahoensis, Stipa columbiana,* and *Potentilla,* and only a slight decrease in *Bromus carinatus.*

Morris (1961) summarized the climax vegetation and successional pattern for an upper elevation range in southwestern Montana. *Festuca idahoensis* and *Stipa columbiana* are the two dominant species. *Bromus carinatus* and *Agropyron trachycaulum* are present but subdominant. *Melica bulbosa* is infrequent in the climax. Forbs make up approximately 25 to 35 percent of the composition, and include *Lingusticum, Senecio, Hieracium, Delphinium,* and *Mertensia. Achillea* and *Lupinus* are present in lesser amounts.

Regressive succession to a distinctly weed stage due to excessive grazing appears to follow this pattern (Morris 1961): *Festuca idahoensis* and *Stipa columbiana* are among the first to disappear, while *Bromus carinatus* and *Agropyron trachycaulum* increase. *Senecio* and *Ligusticum* are replaced by *Helianthus,* which, along with *Bromus carinatus* and *Agropyron trachycaulum,* make up a distinct community. Further regression of the community results in an increase in *Aster engelmannii,* annual forbs, and *Melica bulbosa.* The soils are unstable and excess runoff occurs on weed types or when *Bromus carinatus* and *Agropyron trachycaulum* are the major grass species.

The successional status of *Artemisia tridentata vaseyana* is difficult to establish. Morris and others (1976) indicated that it is probably a seral species that increases its range and density on disturbed sites.

A range may have been overgrazed in the past but may now be improving in condition. The abundance of individual plants in each of the age classes (seedling, young, middle-aged, and old plants) indicates whether a species is maintaining itself, or is increasing or decreasing. A mixture of age classes indicates that a species is maintaining itself in the stand. Improvement may be assumed when the climax species are increasing, and when gullies and other former bare spots are being revegetated (Ellison and others 1951).

Soil Indicators

A stable soil is required for satisfactory range condition on any area where a soil mantle has previously developed. Soil erosion always means a downward trend; thus, range improvement can only occur where the soil is stable (Ellison 1949).

Pickford and Reid (1942) studied the subalpine grasslands of eastern Oregon and eastern Washington. They reported that soil removal by accelerated erosion was an indicator of overgrazing on green fescue (*Festuca viridula*) communities.

Ellison and others (1951) described the evidences of an unstable soil from studies in Utah, Idaho, Washington, and Oregon. They found these signs included rill marks, pedestaled pebbles and plants, tiny alluvial deposits, and gully development. They concluded that small rocks, pebbles, and bunchgrasses on the soil surface protect it from the erosive impact of raindrops, while the surrounding unprotected soil is washed away. Thus, the rocks, pebbles, and bunchgrasses become elevated on low pedestals of soil. Pedestaling was found to be especially useful to indicate current accelerated erosion when storms are of such moderate intensity as not to form gullies or alluvial deposits.

There is no evidence that frost heaving causes pedestals. Frost loosens the soil, may move rocks or pebbles to the soil surface, and can "heave" grass seedlings from the soil and onto the soil surface. However, it is highly unlikely that frost heaving will raise a deep-rooted, fibrous-rooted bunchgrass onto a pedestal.

Substantial evidence demonstrates the negative impacts of excessive grazing on soils in numerous vegetation types. Flory (1936) found that soils on ungrazed, overgrazed, and severely grazed range sites had pore space

of 68.1, 51.1, and 46.5, percent, respectively. Lodge (1954) reported that heavy livestock grazing resulted in soil compaction and reduced moisture-holding capacity; higher successional plant species were replaced by lower successional species that are more competitive under drier conditions.

Willard and Hermann (1977) studied soil water infiltration rates on various range sites in Montana to assess soil compaction by cattle grazing at various times of the year. Infiltration rates were generally highest on ungrazed sites, followed by those sites grazed in winter (when soils are frozen) and fall (when soils are dry). Infiltration rates were lowest on sites grazed during the spring when the soils were wet. Increased soil compaction was associated with increased soil surface erosion and regressive plant succession.

Gullies

Rainfall alone cannot account for the presence of an active gully system cutting into the soil mantle on high-elevation watersheds. Ellison and others (1951) stated that the presence of a soil mantle and a gully system cannot both be normal: the two are irreconcilable. They indicated that the same is true for occurrences of unvegetated soil surfaces, wind-scoured depressions, accelerated soil movement, soil movement by trampling, pedestaling of plants, and widespread accumulation of gravel at the soil surface. On high-elevation ranges these are not compatible with development of a soil mantle on a slope.

Gullies are developed through excessive surface runoff. Bare, steep slopes on a gully generally indicate it is active and the watershed is poorly vegetated. Conversely, when the watershed plant cover is adequate, the gully slopes will be less steep and plants will be establishing both on the slopes and in the channels.

Lichen Lines

The growth of lichens on rocks can often be used as an indication of soil loss around the rock. Lichens grow on the aboveground portions of a rock, usually in the more moist positions on shaded sides and near the ground surface. Soil loss around these rocks can often be detected by observing lichen lines where the soil has been removed at the base of the rock. The lichens are very slow in moving onto the barren areas on the lower rock, thus leaving characteristic "lichen lines" in eroded areas (Ellison and others 1951).

Pocket Gopher Activity

The obvious diggings of pocket gophers on high-elevation ranges leads one to question the influence that these animals have on the soils and vegetation, and whether the gopher influences are natural or are an indirect result of over-grazing. Morris (1961) stated that the amount of gopher activity is directly related to a decline in range condition. He found that as the amount of *Festuca idahoensis* decreased and the amount of forbs together with *Bromus marginatus* and *Agropyron trachycaulum* increased, the amount of gopher activity increased.

Because of the subterranean habitat of gophers, they mostly feed underground. Their food includes fleshy plant parts (taproots, rhizomes, tubers, and corms) found while excavating their runways. Gophers may actually cause an increase in grasses and sedges by feeding on other plant species. Ellison and Aldous (1952) found that *Agropyron* and *Stipa columbiana* increased markedly where gophers were present. They concluded that there is no evidence that gophers have caused a reduction in total production; they may actually have promoted increased production slightly.

No evidence was found by Ellison (1946) that gophers destroy sufficient vegetation to cause accelerated erosion on high-mountain ranges. He also found no evidence that the tunnels of gophers concentrate overland flow sufficiently to create gullies, unless, possibly, abnormal surficial runoff is induced by other causes.

It is generally assumed, then, that pocket gophers only become excessive in numbers and contribute to range deterioration when the normal environment is altered by heavy livestock grazing. There is little or no evidence to contradict this view (Morris 1961).

CURRENT LIVESTOCK MANAGEMENT

Resource values of the whitebark pine ecosystem include water storage and yield, recreation, ecological diversity, wildlife, minerals, small amounts of firewood, and livestock grazing. Concerns with resource value conflicts between livestock grazing and other values, along with changes in livestock economics and grazing policy, have led to a general decline in livestock numbers in the whitebark pine ecosystem from the early 1950's to the present. In general, range condition is improving as livestock numbers are reduced and better management is applied.

High-elevation ranges are more suited to sheep than cattle grazing. However, sheep numbers have declined as cattle numbers have increased throughout the West. For example, from 1925 to 1982, sheep numbers in Montana declined from approximately 2.2 million to 0.6 million, while cattle numbers increased from about 1.1 million to 2.9 million (U.S. Bureau of the Census 1983). These changes have generally led to a decreased demand for high-elevation grazing.

Numerous grazing allotments in National Forests are currently vacant; many have been for 25 years of more. These allotments are being closed because of the absence of suitable range, changes in use from sheep to cattle, and resource conflicts. Many of the sheep allotments were closed in the 1950's and 1960's for resource protection on high-elevation ranges.

in wilderness areas is for packstock. For example, there are about 17,000 acres in packstock allotments in wilderness in the Bitterroot National Forest (USDA Forest Service 1987). The Flathead National Forest had 2,664 AUM's allocated to recreationists' stock and government administrative stock in wilderness in 1980 (USDA Forest Service 1985).

FUTURE OF GRAZING IN THE WHITEBARK PINE ECOSYSTEM

Various factors will interact to determine the future of livestock grazing in the whitebark pine ecosystem. These factors are mostly negative on public lands and mixed on private lands. Factors on public lands will include the following: wilderness designation of new areas, increased emphasis on recreation, conflicts between livestock and big game, increase in grizzly bears and introduction of wolves, improved riparian area management, and increased stress for range improvement. Factors important on private lands will include cost/benefits of producing livestock, availability of herders and riders, use of sheep to control weeds, and development of fee hunting of big game as an alternative to livestock production.

Livestock grazing in the whitebark pine ecosystem is expected to continue to decline on public lands and will probably remain constant on private lands. Since whitebark pine occurs mostly on public lands, most of the livestock grazing will be reduced within this ecosystem.

CONCLUSIONS

The whitebark pine ecosystem has been an important source of livestock foraging since the late 1800's. The large bands of sheep that grazed these ranges during the "open range" period caused considerable, sometimes irreversible, damage to the soils and natural vegetation. As these lands have come under management, the grazing pressure has been reduced, many allotments have been closed, and partial recovery has occurred.

In judging the impacts of present management, it is important to determine range condition and trend. These can be determined by using plant community and soil indicators. A range overgrazed in the past may now be improving in condition; conversely, a range in good condition may be deteriorating. The abundance of plants in each age class indicates whether a species is maintaining itself, or is increasing or decreasing. Improvement implies an increase in climax plant species and active revegetation of gullies and other former bare spots.

With the growing concern for protecting the whitebark pine ecosystem, along with an increase in poisonous plants, establishment of wilderness areas, decreased interest in herding livestock, and difficulty of ready access to these areas, there has been a steady decline of livestock grazing in this ecosystem. Conflicts with other uses will probably lead to further declines in livestock use.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from Linda Meriglaino)—What evidence do you have to support that pocket gophers only come in after excessive grazing?

A.—It was not my intent to imply that pocket gophers are not present before excessive grazing occurs. Rather, pocket gophers are present only in small numbers on high elevation grasslands in good to excellent condition. As indicated by the studies reviewed in this paper, pocket gophers eat fleshy underground plant parts, not fibrous roots of grasses. Thus, the climax grasses must be reduced by excessive livestock grazing to allow forbs and rhizomatous grasses to enter the stand in such density to support high densities of pocket gophers.

Q. (from Sandy Kratville)—If we do receive increased horse use of high elevation ranges - what would you recommend to reduce impacts to these areas?

A.—The best way to reduce horse use and associated disturbances is to reduce the number of horses and the amount of time they spend on a specified area. This can be partially accomplished by regulating the number of horses using a particular trail system, and by limiting the time they spend on each of the meadows and grasslands; reduce the number, disperse them to the extent possible, and keep them moving.

EXOTIC INVASION OF TIMBERLINE VEGETATION, NORTHERN ROCKY MOUNTAINS, USA

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ABSTRACT

Thirty-five exotic species were found in vegetation characteristic of Northern Rocky Mountain timberlines. At least 20 percent were intentionally introduced along roadsides. The diversity of invading exotics declined from subalpine to alpine vegetation. While exotic diversity generally increased with increasing disturbance, severe trampling excluded some species from road-shoulder sites. The exotics of greatest concern to wildland managers are Phleum pratense *(timothy) and* Poa pratensis *(Kentucky bluegrass) because they establish widely, spread vigorously, and usually escape early detection. Control of any exotic should involve its eradication and simultaneous introduction of desirable competitors to minimize reinvasion.*

INTRODUCTION

Timberline in the Northern Rocky Mountains is usually bordered above by alpine vegetation (Bamberg and Major 1968; Johnson and Billings 1962) and below by either subalpine forests—often subalpine fir-whortleberry (*Abies lasiocarpa-Vaccinium scoparium*, Daubenmire and Daubenmire 1968; Pfister and others 1977)—or subalpine meadows—often Idaho fescue-wheatgrass (*Festuca idahoensis-Agropyron caninum*, Mueggler and Stewart 1980). Whitebark pine often occurs at and below timberline and tends to dominate on relatively dry sites (Arno and Weaver, this proceedings). Since vegetation tends to vary continuously along environmental gradients, we believe that our observations of exotic weed invasion of adjacent forest, meadow, and tundra vegetation types also will apply to most timberline and whitebark pine vegetation types with similar understories.

Our studies of exotic invasion of major vegetation types of the Northern Rocky Mountains have concentrated on two questions:

1. Which exotics are capable of invading each environmental zone—habitat type (HT, Daubenmire 1968, 1970)?

2. Within an environmental zone, how much disturbance is required for success of the exotic; that is, does the plant require continuous disturbance or can it invade even undisturbed vegetation?

METHODS

To determine which exotics can invade major environmental zones of the Northern Rocky Mountains (question 1), we listed those present in each of 16 environmental types (= habitat types, HT's) ranging from dry grasslands up through forests to the alpine (Weaver and others 1989). Three of these HT's are found at timberline (*Abies lasiocarpa-Vaccinium scoparium* forests, *Festuca idahoensis-Agropyron caninum* meadows, and alpine tundra; Weaver and others 1989) and therefore represent whitebark pine understories. We sampled only roadside sites because these have a high probability of inoculation; that is, species absences there are likely due to the physical-biological environment rather than lack of seed. Ten sites were examined in each environmental zone (HT). At each site the five disturbance conditions described below were examined to ensure that exotics specific to any disturbance condition were included. As it turned out, this site reconnaissance—which examined far larger areas—identified few exotics not found in specific plots used to answer our second question.

Knowledge of the environmental zones (HT's) an exotic can occupy does not reveal the degree to which the plant will dominate the HT considered; will it occupy only highly disturbed areas or will it spread to undisturbed vegetation? To determine the capacity of an exotic to spread (question 2), we sampled sites experiencing the range of disturbance conditions (DC's) expected in the HT: constant heavy disturbance, periodic light disturbance, one-time heavy disturbance followed by primary succession, one-time light disturbance followed by secondary succession, and no disturbance. These DC's appear at roadsides in the form of shoulder, ditch slope, cutbank, logged right-of-way, and undisturbed vegetation of our National Parks, respectively. Exotic dominance was sampled in each DC in a 0.5- by 25-m macroplot running parallel to the road. Presence was recorded in each macroplot for plot constancy calculations; constancy indicates regional ubiquity and is calculated as the percent of the 10 sites in an environmental zone and across all disturbance conditions (HT) or a disturbance zone within

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an environmental zone (HT-DC) occupied by the plant. Presence was also recorded in five 0.5- by 5-m subplots for frequency calculations; frequency indicates local ubiquity and is measured, for example, as the percent of five subplots in a macroplot occupied by the species. Cover was measured with 75 points lowered along the centerline of the macroplot; it indicates the degree to which the ground surface is covered by a particular species.

PRESENCE BY HABITAT

Our studies of vegetation above and below timberline suggest that 34 exotic species tolerate timberline environments of the Northern Rocky Mountains and show that these species differ considerably in the consistency of their presence among sites in an environmental type (constancy; table 1, column 2). Exotic diversity (richness)

Table 1—Constancy and infected site frequency of exotic species in three environmental types and five disturbance conditions. The species are listed in approximate order of their abilities to invade closed vegetation

	Constancy[2]	Disturbance condition[3] (infected site frequencies > 20 percent)				
Exotic species[1]	**F.M.A.**	**Shoulder-constantly**	**Ditch-periodic**	**Roadcut-once (1°)**	**Logged-once (2°)**	**Climax-never dist.**
Phleum pratense	99.99.36	FM	FM	FM		M
Poa pratensis	99.99.00	FM	FM	FM	F	M
Polygonum aviculare	60.60.00	FM	FM		F	M
Taraxacum officinale	99.99.91	FMA	FMA	FM	F	M
Descurainia pinnata	00.50.00		M	M		M
Festuca rubra	00.00.09					A
Madia glomerata	60.50.00	FM	FM	FM	F	
Lychnis alba	10.00.00			F		
Thlaspi arvense	00.10.00			M		
Tragopogon dubius	10.10.00		M	F		
Trifolium hybridum	99.90.00	FM	FM	FM		
Trifolium repens	90.30.00	FM	F	M		
Agrostis alba	60.40.00	FMA	FM	F		
Bromus inermis	50.99.36	FMA	FM	F		
Dactylis glomerata	50.00.00	F	F	F		
Matricaria matricari.	60.20.00	FM	FM	M		
Medicago lupulina	80.60.00	FM	FM	F		
Melilotus officinalis	40.70.00	F	FM	F		
Agropyron repens	30.00.00	F	F			
Arabis glabra	20.00.00	F	F			
Festuca pratensis	30.10.09	A	FM			
Plantago major	20.00.00	F	F			
Poa compressa	20.50.27	MA	FM			
Cirsium arvense	10.00.00		F			
Cirsium vulgare	10.00.00		F			
Lactuca serriola	10.00.00		F			
Medicago sativa	10.00.00		F			
Rumex crispus	20.00.00		F			
Tanacetum vulgaris	10.00.00		F			
Capsella bursa-past.	30.00.00	M				
Verbascum thapsus	10.00.00	F				
Alyssum alyssoides	20.00.00					
Rumex acetosella	00.00.36					
Trifolium pratense	20.00.00					

[1]Column 1 lists all exotics found in three HT's—a forest (F = *Abies lasiocarpa-Vaccinium scoparium*, Pfister and others 1977), a subalpine meadow (M = *Festuca idahoensis-Agropyron caninum*, Mueggler and Stewart 1980), and alpine tundra (Johnson and Billings 1962). Eleven alpine sites were sampled along the Beartooth Highway; 10 mountain meadows and 10 subalpine fir forests were sampled in and around Grand Teton National Park. Nomenclature follows Hitchcock and Cronquist (1973); abbreviated names are *C. bursa-pastoris* and *M. matricarioides*.

[2]Column 2 gives the constancy of each species in the forest (F), meadow (M), and alpine tundra (A) environments; that is, the percent of sites at which the exotic species was present in the area encompassed by five 0.5- by 25-m plots, one in each disturbance zone. In two cases a species, not present in the plots, was recorded outside; site constancies were slightly higher than plot constancies in these cases: *Taraxacum* 99.99.99 and *Bromus inermis* 50.99.45. Column 2 can be summarized by counting numbers of present exotics (cn > 10 percent, 30.17.07), common exotics (cn > 30 percent, 13.12.04), and universal exotics (cn > 80 percent, 05.05.01) in the forest, meadow, and alpine environments, respectively.

[3]Columns 3 through 7 indicate the disturbance conditions where, at infected sites, the species had a frequency higher than 20 percent; that is, the species occurred in more than 20 percent of the 1- by 5-m plots sampled at infected sites in that disturbance condition. The disturbance conditions considered include undisturbed (Climax-never dist.), secondary succession on cleared right-of-way (Logged once (2°)), primary succession on roadcuts (Roadcut-once (1°)), periodically disturbed ditch slope (Ditch-periodic), and constantly disturbed road shoulder (Shoulder-constantly). The environments where the frequency exceeded 20 percent are indicated by F (forest), M (meadow), and A (alpine tundra).

declines from 30 species in subalpine forests to 17 species in subalpine meadows, to seven species in alpine tundra. Wildland managers should notice that 20 to 30 percent of the high-frequency exotics (table 1, columns 3 through 7) have been intentionally introduced in roadside seedings.

Vaccinium scoparium (whortleberry) dominates the understories of the major forest habitats, such as *Abies lasiocarpa-Vaccinium scoparium, Pinus albicaulis-Vaccinium scoparium, Abies lasiocarpa-Pinus albicaulis-Vaccinium scoparium* (Pfister and others 1977). In this vegetation we found 30 exotic associates, of which 13 occurred in over 30 percent of the stands and five occurred in over 80 percent of the stands (table 1).

Festuca idahoensis-Agropyron caninum meadows occupy drier sites in the subalpine zone and serve as an understory in *Pinus albicaulis-Festuca idahoensis* woodlands. These meadows contained 17 exotic species, of which 12 occurred at over 30 percent of the sites, five occurred at over 80 percent of the sites, and only two—*Descurainia pinnata* (tansey mustard) and *Thlaspi arvense* (pennycress)—were not observed as colonizers in whortleberry understories (table 1).

Alpine vegetation appears around and among trees—whitebark pine (*Pinus albicaulis*), subalpine fir, and Engelmann spruce (*Picea engelmannii*) at upper timberline. In this vegetation we found seven exotic species, of which four appeared in over 30 percent of the stands, one appeared in over 80 percent of the stands, and only two, *Festuca rubra* (red fescue) and *Rumex acetosella* (sheep sorrel), were not observed in whortleberry understories (table 1).

PRESENCE BY DISTURBANCE CONDITION

Exotic species that invade undisturbed climax vegetation are of greatest concern to managers opposed to the modification of natural vegetation. We recorded no exotic colonization of forests with undisturbed whortleberry understories (table 2); the absence of exotics in closed forest stands is probably due to the high sun requirements of the plants introduced. Six exotic species were present in over 30 percent of the meadow sites occupied by the exotic species (table 3). Three species, *Festuca rubra*, *Poa compressa* (Canada bluegrass), and *Taraxacum officinale* (dandelion), were present in over 30 percent of the occupied alpine sites (table 4). Most of these colonizers had frequencies over 20 percent; that is, they occurred in over 20 percent of the 0.5- by 5-m quadrats sampled. Throughout this section, and in tables 2, 3, and 4, disturbed site constancy is expressed on the basis of infected sites because our object is to express the capacity of species present to invade variously disturbed zones. If readers want to calculate conventional constancies they can use disturbed site constancy and total constancy (from table 1) to do so; for example, if the disturbed site infected-constancy were 50 percent and the total constancy were 50 percent the disturbed site total-constancy would be 25 percent.

Exotic species that colonize secondary succession sites such as logged or burned sites are also of concern because large areas are involved and their dominance might slow succession. Of 13 invaders found on logged *Abies lasiocarpa-Vaccinium scoparium* sites, six had constancies over 30 percent and four had frequencies of 20 percent or more (table 2). While this disturbance condition does not exist in meadow and alpine sites, it exists potentially (unstudied) in high-altitude whitebark or limber pine (*Pinus flexilis*) woodlands.

Topsoil removal leading to primary succession, while less common than the community destruction considered above, does occur on roadcuts, riverbanks, and landslides. Fourteen, 10, and two exotic species had constancies over 30 percent on roadcuts in forest, meadow, and alpine zones respectively (tables 2, 3, and 4). Sixteen species had frequencies of over 20 percent on primary succession sites in at least one environmental type (table 1). Two exotics—*Lychnis* (campion) and *Thlaspi* (pennycress)—that were restricted to primary succession sites in our sample are known to occupy repeatedly disturbed sites elsewhere.

Ditch slopes are periodically influenced by humans; they may be mowed, watered, sanded, lightly compacted, sprayed with herbicide, or salted. Twenty-eight, 13, and four species had constancies over 30 percent on infected sites in forest, meadow, and alpine respectively (tables 2, 3, and 4). Infected site frequencies of 20 percent or more were observed for 20 species in this disturbance condition (table 1).

Road shoulders are constantly disturbed by people with heavy trampling, mowing, watering, sanding, heavy compaction, herbicides, or salt. Twenty-two, 15, and six species had constancies over 30 percent on infected sites in forest, meadow, and alpine zones, respectively (tables 2, 3, and 4). Infected site frequencies over 20 percent were observed for 21 species in this disturbance condition (table 1).

Numbers and frequencies of species generally increase as one moves from undisturbed to regularly disturbed sites (right to left in tables 1 to 4). We believe such increases occur primarily because resources are more available to individuals on more disturbed sites—both because competition is increasingly reduced and because supplements, especially runoff water, begin to appear. Diversity increases might also be due to a constant reintroduction of species, such as *Chenopodium album* (lambsquarter), which are unlikely to reproduce or spread away from the road. At timberline, half of the exotics such as *Plantago major* (broadleaf plantain) are restricted to high-resource, low-competition shoulder and ditch sites (table 2).

Due to the interaction of disturbance and trampling, the increase in species richness ceases when one moves to the road shoulder (tables 1 to 4). Further increases in water and sun, decreased competition, or continual introduction support the increase of several species such as *Capsella bursa-pastoris* (shepherdspurse), *Chenopodium album* (lambsquarter), and *Verbascum thapsas* (mullien).

Table 2—Exotic invasion of five disturbance zones in ABLA-VASC forests as indexed by percent constancy, percent frequency, and percent cover at infected sites. Blanks separated by periods indicate zeros

	Disturbance zone[1] and presence[2]				
	Shoulder-constantly	Ditch-periodic	Roadcut-once (1°)	Logged-once (2°)	Climax-never dist.
Exotic species[2]	cn fq cv	cn fq cv	cn fq cv	cn fq cv	cn fq cv
Verbascum thapsus	99.20. 0.	. . .	. . .	. . .	. . .
Agropyron repens	33.27. 2.	99.40. 5.	. . .	. . .	. . .
Alyssum alyssoides	50.10. 0.	50.10. 0.	. . .	. . .	. . .
Arabis glabra	99.20. 0.	99.30. 1.	. . .	. . .	. . .
Capsella bursa-past.	67.20. 0.	33. 7. 0.	. . .	. . .	. . .
Chenopodium album	50.10. 0.	50.10. 0.	. . .	. . .	. . .
Festuca pratensis	33.13. 0.	67.33. 2.	. . .	. . .	. . .
Matricaria matricari.	83.53. 1.	67.30. 2.	. . .	. . .	. . .
Plantago major	99.40. 1.	99.50. 1.	. . .	. . .	. . .
Cirsium arvense	. . .	99.40. 0.	. . .	. . .	. . .
Cirsium vulgare	. . .	99.20. 0.	. . .	. . .	. . .
Lactuca serriola	. . .	99.20. 0.	. . .	. . .	. . .
Medicago sativa	. . .	99.99.12.	. . .	. . .	. . .
Poa compressa	. . .	99.30. 1.	. . .	. . .	. . .
Rumex crispus	. . .	99.20. 1.	. . .	. . .	. . .
Tanacetum vulgare	. . .	99.20. 0.	. . .	. . .	. . .
Lychnis alba	. . .	. . .	99.40. 0.	. . .	. . .
Tragopogon dubius	. . .	. . .	99.20. 0.	. . .	. . .
Agrostis alba	99.53. 7.	83.57.13.	67.23. 0.	17. 7. 0.	. . .
Bromus inermis	99.64. 8.	80.60. 6.	80.56. 5.	60.16. 1.	. . .
Dactylis glomerata	99.48. 4.	99.48. 4.	40.28. 0.	20. 4. 0.	. . .
Madia glomerata	67.33. 1.	83.63. 4.	83.43. 1.	33.20. 0.	. . .
Medicago lupulina	63.55. 3.	75.50. 2.	50.30. 2.	13. 5. 0.	. . .
Melilotus officinalis	99.50. 2.	75.75. 5.	75.60.17.	25.15. 1.	. . .
Phleum pratense	90.82. 7.	90.68. 5.	80.50. 1.	30. 6. 0.	. . .
Poa pratensis	90.74.11	90.54. 3.	40.30. 1.	30.20. 0.	. . .
Polygonum aviculare	83.47. 2.	67.47. 2.	67.17. 0.	50.23. 0.	. . .
Taraxacum officinale	99.76. 5.	99.82. 4.	80.64 . 3.	80.48. 2.	. . .
Trifolium hybridum	80.54. 7.	60.58. 9.	80.60. 7.	40.16. 0.	. . .
Trifolium pratense	50.10. 0.	50.10. 0.	0. 0. 0.	50.10. 0.	. . .
Trifolium repens	44.31. 3.	89.62. 9.	44.18. 0.	11. 7. 0.	. . .

[1]Site and type of disturbance were: constantly and heavily disturbed road shoulder (Shoulder-constantly), periodically and lightly disturbed ditch (Ditch-periodic), once heavily disturbed with soil removal (Roadcut-once 1°), once moderately disturbed without soil removal (Logged-once 2°), and undisturbed climax (Climax-never dist.).

[2]Exotic presence at infected sites is reported with constancy (cn = percent of infected sites occupied), frequency (fq = percent of 0.5- by 5-m subsites occupied at infected sites), and cover (cv = percent of ground covered at infected sites). Data are based on 10 sites sampled in the Grand Teton National Park area.

Simultaneously, trampling at the road shoulder eliminates brittle-stemmed species such as *Cirsium* (thistle), *Lactuca* (lettuce), and *Tanacetum* (tansey) that would undoubtedly thrive in its absence. Species that do survive on roadshoulders seem to do so (Dale and Weaver 1974) via flexibility (as with grasses and clovers, especially bluegrass, timothy, clover, and sweetclover), stemless forms (such as plantain, dandelion, and mullien), creeping forms (such as knotweed), and avoiding destruction with short life cycles or growth in the off-season (as illustrated by rockcress and shepherdspurse).

MANAGEMENT

As noted above, the exotics of greatest concern are those capable of leaving the roadsides and invading little-disturbed or undisturbed native vegetation. For the upper forest and alpine zones these include *Phleum pratense* (timothy), *Poa pratensis* (Kentucky bluegrass), *Polygonum aviculare* (prostrate knotweed), *Taraxacum officinale* (dandelion), *Descurainia pinnata* (tansey mustard), and *Festuca rubra* (red fescue). *Phleum pratense* and *Poa*

Table 3—Exotic invasion of five disturbance zones in FEID-AGCA meadows as indexed by percent constancy, percent frequency, and percent cover at infected sites. Dashes indicate a nonexistent zone and blanks separated by periods indicate zeros

	Disturbance zone[1] and presence[2]				
	Shoulder-constantly	Ditch-periodic	Roadcut-once (1°)	Logged-once (2°)	Climax-never dist.
Exotic species[2]	cn fq cv	cn fq cv	cn fq cv	cn fq cv	cn fq cv
Chenopodium album	99.40. 0.	. . .	. . .	- - -	. . .
Agrostis alba	25.20. 1.	99.30. 1.	. . .	- - -	. . .
Bromus inermis	80.50. 4.	80.36. 2.	. . .	- - -	. . .
Festuca pratensis	. . .	99.40. 0.	. . .	- - -	. . .
Tragopogon dubius	. . .	99.20. 1.	. . .	- - -	. . .
Matricaria matricari.	50.30. 1.	50.30. 1.	50.20. 1.	- - -	. . .
Poa compressa	60.28. 2.	60.32. 2.	20. 4. 0.	- - -	. . .
Trifolium hybridum	78.44. 2.	78.60. 5.	67.24. 1.	- - -	. . .
Trifolium repens	67.27. 1.	33. 7. 0.	33.27. 1.	- - -	. . .
Thlaspi arvense	. . .	. . .	99.20. 0.	- - -	. . .
Descurainia pinnata	20.12. 0.	40.20. 1.	40.32. 1.	- - -	80.28. 1.
Madia glomerata	40.20. 0.	80.56. 1.	40.28. 0.	- - -	40.12. 0.
Melilotus officinalis	71.17. 1.	57.20. 0.	14.11. 0.	- - -	14. 6. 0.
Phleum pratense	60.32. 0.	99.60. 1.	70.40. 1.	- - -	60.30. 0.
Poa pratensis	90.76. 3.	90.68. 3.	70.40. 3.	- - -	50.22. 0.
Polygonum aviculare	33.20. 2.	83.40. 2.	0. 0. 0.	- - -	33.23. 0.
Taraxacum officinale	90.88. 7.	99.88. 5.	99.60. 1.	- - -	60.32. 0.

[1]Site and type of disturbance were: constantly and heavily disturbed road shoulder (Shoulder-constantly), periodically and lightly disturbed ditch (Ditch-periodic), once heavily disturbed with soil removal (Roadcut-once 1°) once moderately disturbed without soil removal (Logged-once 2°), and undisturbed climax (Climax-never dist.)

[2]Exotic presence at infected sites is reported with constancy (cn = percent of infected sites occupied), frequency (fq = percent of 0.5- by 5-m subsites occupied at infected sites), and cover (cv = percent of ground covered at infected sites). Data are based on 10 sites sampled in the Grand Teton National Park area.

Table 4—Exotic invasion of five disturbance zones in the alpine tundra environment, as indexed by percent constancy, percent frequency, and percent cover at infected sites. Dashes indicate a nonexistent zone and blanks separated by periods indicate zeros

	Disturbance zone[1] and presence[2]				
	Shoulder-constantly	Ditch-periodic	Roadcut-once (1°)	Logged-once (2°)	Climax-never dist.
Exotic species[2]	cn fq cv	cn fq cv	cn fq cv	cn fq cv	cn fq cv
Festuca pratensis	99.20. 0.	. . .	. . .	- - -	. . .
Bromus inermis	75.25. 0.	25. 5. 0.	. . .	- - -	. . .
Phleum pratense	50.10. 0.	50.10. 0.	25. 5. 0.	- - -	. . .
Poa compressa	67.40. 0.	33. 7. 0.	0. 0. 0.	- - -	33. 7. 0.
Taraxacum officinale	90.62. 1.	80.60. 1.	40.10. 0.	- - -	10. 2. 0.
Rumex acetosella	50. 5. 0.	50.15. 0.	25.15. 0.	- - -	75.15. 0.
Festuca rubra	. . .	. . .	99. 0. 0.	- - -	99.40. 0.

[1]Site and type of disturbance were: constantly and heavily disturbed road shoulder (Shoulder-constantly), periodically and lightly disturbed ditch (Ditch-periodic), once heavily disturbed with soil removal (Roadcut-once 1°) once moderately disturbed without soil removal (Logged-once 2°), and undisturbed climax (Climax-never dist.)

[2]Exotic presence at infected sites is reported with constancy (cn = percent of infected sites occupied), frequency (fq = percent of 0.5- by 5-m subsites occupied at infected sites), and cover (cv = percent of ground covered at infected sites). Data are based on 10 sites sampled in the Beartooth Plateau area.

pratensis are of special concern because they often dominate the areas they occupy. Because we sampled along long-established roads, we believe that most invaders that have occupied the region for long periods of time have been introduced, have been naturally tested, and are unlikely to invade further. Any plants currently establishing in the region, however (like, but probably not including leafy spurge [*Euphorbia esula*]), have not been tested naturally and could conceivably become important at timberline. While most new introductions fail to establish, some establish in limited areas and small numbers and, presumably after either a "fitting mutation" or some natural or human-caused environmental change, spread widely (Krebs 1985). Plants that have only established well on roadsides in timberline environments are of little concern in this vegetation zone (because they occupy little area and have been well tested for escape), but should perhaps be controlled if roadsides through this zone serve as corridors for invasion of other habitats. Control of any exotic species should involve both elimination and simultaneous introduction of a desirable competitor to minimize reinfection.

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USE OF FOREST ECOSYSTEM PROCESS MEASUREMENTS IN AN INTEGRATED ENVIRONMENTAL MONITORING PROGRAM IN THE WIND RIVER RANGE, WYOMING

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ABSTRACT

Three forest ecosystem processes—conifer needle retention, canopy litterfall, and litter decomposition—were measured as part of an integrated environmental monitoring program at a high-elevation site dominated by whitebark pine (Pinus albicaulis) *and Engelmann spruce* (Picea engelmannii). *Whitebark pine demonstrated much lower needle retention rates and slightly slower decomposition rates relative to Engelmann spruce. Studies to date reflect low productivity at this site and will provide baseline data against which future monitoring data may be compared.*

INTRODUCTION

This paper reports on forest ecosystem process measurements at an integrated environmental monitoring site located in a high-elevation, whitebark pine/Engelmann spruce (*Pinus albicaulis/Picea engelmannii*) system in the Wind River Mountains of western Wyoming. Ecosystem process measurements emphasized include conifer needle retention, canopy litterfall, and litter decomposition rates. Nutrient analyses were also conducted on conifer needles and litter samples. The primary objectives of this paper are: (1) to describe the rationale for applying these measurements to a monitoring program, (2) to summarize and discuss the data collected to date, and (3) to compare data with those collected at other remote sites.

This study represents an extension of previous monitoring and research conducted at other remote sites including national and international Biosphere Reserves and U.S. National Parks and wilderness areas (for example, Bruns and others 1982, 1984; Wiersma and others 1984; Wiersma and Otis 1986). In addition to the Wind River program, other sites that have been studied include Olympic National Park in Washington (Brown and Wiersma 1979), Noatak National Preserve and Biosphere Reserve in Alaska (Wiersma and others 1986), and Torres del Paine National Park in southern Chile (Bruns and Wiersma 1988a; Wiersma and others 1988). The basic objective of each of these monitoring programs is to provide the baseline data necessary to define the "natural" conditions at the site. This in turn allows better interpretation of the impacts of human activities on the system. A further goal of the Wind River monitoring program is to field test guidelines established by the U.S. Department of Agriculture, Forest Service, for monitoring the condition of remote, wilderness ecosystems (Fox and others 1987).

SYSTEMS APPROACH

An integrated, multimedia systems approach has been implemented in the Wind River monitoring program (Bruns and Wiersma 1988b). The design of the program is based on a watershed/drainage basin perspective (for example, Likens 1985; Minshall and others 1985), and links together key aspects of the forest, soil, stream, and lake components along selected pathways within the system (Bruns and Wiersma 1988b). This approach begins with the development of a simple conceptual design of the system to be monitored. This conceptual design is translated into a schematic diagram such as that shown in figure 1. Such diagrams are intended as heuristic tools for identifying system compartments of primary concern, delineating potential pollutant pathways through the system, and identifying potential critical pollutant receptors. This allows us to view the problem as one of pollutant sources and pathways to critical receptor components of the ecosystem. The ultimate goal of such a program is to identify a list of pollutant and ecosystem measurements capable of providing good, quality-assured data against which future observations may be compared, allowing us to assess the relative condition of the system.

The integrated ecosystem approach to environmental monitoring used in the Wind River monitoring program

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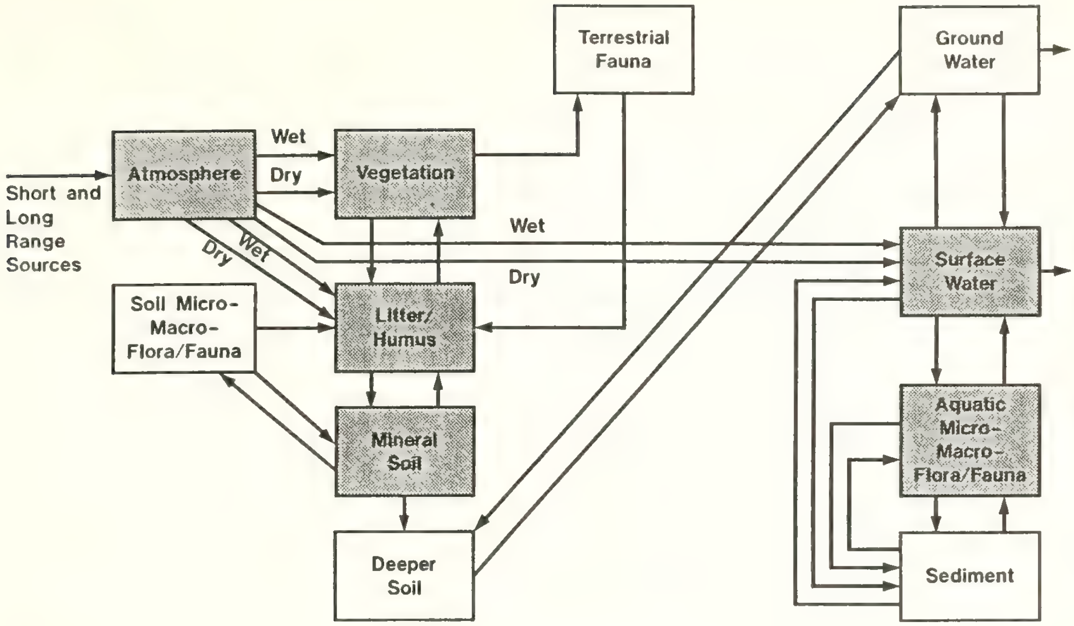

Figure 1—Conceptual approach to monitoring sensitive wilderness systems. Shaded compartments are included in the monitoring program.

involves the collection of two basic types of information: analyses of multimedia environmental samples, and measurement of terrestrial and aquatic ecosystem processes identified as potential indicators of pollutant impact to the system. Components examined in the monitoring program include the atmosphere, soils, aquatic chemistry, aquatic biology, salmonid fish, and vegetation. Specific methods and procedures used are provided elsewhere (Bruns and Wiersma 1988b; Bruns and others 1987, 1988; Fox and others 1987). The emphasis of this paper is on the portion of the program involving the measurement of forest ecosystem processes.

FOREST ECOSYSTEM PROCESSES

The measurement of parameters related to various ecosystem processes can be used to monitor changes in ecosystem condition (Baker and others 1986). To function adequately as an indicator of pollutant impact, an ecosystem parameter should satisfy the following criteria: (1) it should adequately reflect a process or function of the ecosystem, (2) it should respond to the input of an environmental pollutant in some predictable manner, (3) it should be measurable through time, (4) a small natural variability should be associated with it, and (5) the precision associated with the measurement of the parameter should be adequate to observe departures from the norm (Hinds 1984; McShane and others 1983). Needle retention, canopy litterfall, and litter decomposition rates were chosen because they appeared to meet these criteria, and because they had been established in previous investigations on ecosystem response to atmospheric pollutants.

Premature needle loss and the associated change in litterfall rate have been shown to be related to the input of air pollutants either due to the direct action of the pollutant on needle or leaf surfaces or due to damage to root systems caused by increased soil acidity (Mann and others 1980; Ulrich 1981; Williams 1980). Litter decomposition may also be affected due to heavy metal inputs (Coughtrey and others 1979; Strojan 1978), pH changes (Moloney and others 1983), or indirectly in response to changes in litterfall characteristics resulting in litter input containing higher nitrogen concentrations relative to lignin (Melillo and others 1982). The potential for disruption of nutrient cycles or primary productivity may therefore increase. Increases in tree mortality have also been associated with airborne pollution in North America and Europe (Freedman and Hutchison 1980).

The methodologies used to measure forest ecosystem processes in this program have been previously used in the Hoh Rain Forest of Olympic National Park (Baker and others 1986). Changes in needle retention, litterfall, and litter decay rates can result in changes in productivity and mortality. Observation of these processes allows the establishment of a broader basis on which to explain changes in the system. The range of natural variability in an ecosystem is an important consideration in the design of a monitoring program (Miller 1984). It may be difficult to distinguish between natural ecosystem variability and pollutant-induced change in the presence of extreme environmental conditions, short periods of pollutant exposure, or early stages of pollutant input. In such cases, the use of parameters with known and predictable fluctuations as indicators would aid in making that distinction.

A hypothetical response of needle retention, canopy litterfall, and tree mortality in response to the input of atmospheric pollutant is shown in figure 2. In response to pollutant input, conifer needle retention rates have been shown to decline significantly (Mann and others 1980; Williams 1980), typically with the youngest needles showing the greatest impact (Ulrich 1981). In response to the decrease in needle retention times, litterfall rates

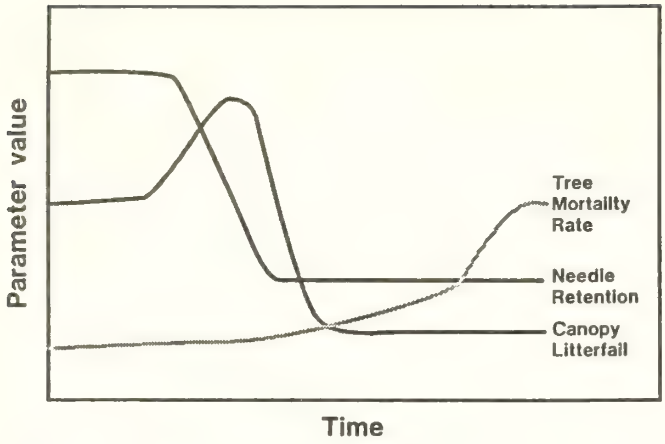

Figure 2—Hypothetical interactions between forest ecosystem parameters to input of atmospheric pollutants.

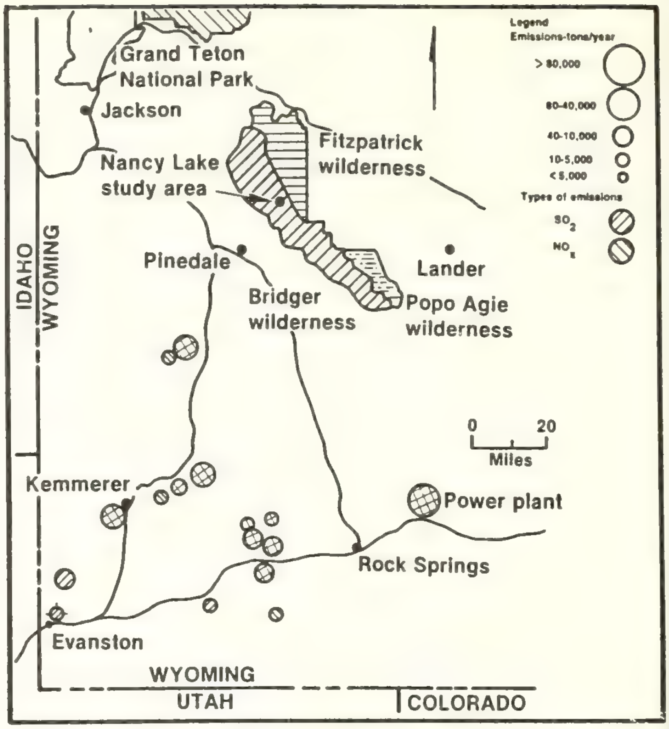

Figure 3—General location of the Wind River study site. Permitted point sources for SO_2 and NO_2 are also shown. Map based on USDA Forest Service (1984).

would be expected to increase initially, before decreasing and ultimately leveling off at a lower level. Similarly, the reduction in active photosynthetic area associated with decreased needle retention would be expected to contribute to the overall mortality rate of the stand, although other factors would undoubtedly impact the mortality rate as well.

Litter decomposition rate also plays an important role in nutrient recycling in forest ecosystems, and is influenced by many factors (Fogel and Cromack 1977). Alterations in nutrient release rates, therefore, may have an impact on tree growth and survival. Decomposition rate is not shown on figure 2, due to the difficulties associated with predicting the response of litter decomposition rates to the input of atmospheric pollutants. Pollutant input can have a detrimental effect on the organisms responsible for much of the decay, resulting in a decrease in the total rate of decay. The lignin-nitrogen ratio of the needles shed by the conifers may also play a significant role. If the response of the trees in the canopy is to prematurely shed younger needles, the lower lignin/nitrogen ratios typically associated with younger foliage may contribute to an increase in the decay rate of the litter (Melillo and others 1982).

The intent of the model proposed in figure 2 is to integrate ecosystem response to atmospherically deposited pollutants in remote areas. The long-term goal of this study is to test these and other hypotheses against future changes in pollutant levels.

STUDY SITE

The study site is located at Nancy Lake, in the upper portion of the Hobbs Lake watershed within the Bridger Wilderness Area of the Bridger-Teton National Forest, WY (fig. 3). Nancy Lake is located at an elevation of 3,140 m (10,400 ft), and is approximately 2 ha (5 acres) in surface area. Soils at the study area are thin, and the area is sparsely forested with Engelmann spruce and whitebark pine, interspersed with small numbers of subalpine fir (*Abies lasiocarpa*). Some environmental monitoring previously had been conducted by the Forest Service in the area (USDA FS 1984). The study site was originally chosen because of the presumed sensitivity of high-mountain ecosystems to atmospheric pollutants, the presence of other ongoing complementary monitoring projects, relatively easy access to the site, and potential for the area to receive measurable pollutant input from energy development activities upwind (fig. 3). As such, the Wind River Mountains provide an ideal location for an integrated monitoring project (Wiersma and others 1985).

METHODS

Permanent Reference Stands

Two permanent 0.25-ha (0.6-acre) study plots were established within different forest patches during the 1987 field season. The plots are referred to as BR-1 and BR-2, and were chosen to reflect the basic forest types found in the Nancy Lake area. These forest types fit into the habitat types described by Steele and others (1983); BR-1 represents the *P. engelmannii/Vaccinium scoparium* type and BR-2 represents the *P. albicaulis* phase of the *A. lasiocarpa* type. Plot boundaries were surveyed with compass and meter tapes. Diameters of all trees greater than 1-cm diameter at breast height (d.b.h.) were measured, and these trees were tagged.

Conifer Needle Retention

Branches were selected for use in determining needle retention from whitebark pine and Engelmann spruce, the two dominant tree species found in the area. Single branches were sampled from five trees of each species, for each stand. Each branch was placed in a plastic bag, labeled, and was returned to the laboratory for counting. All were placed in a refrigerated room within 36 hours of collection, and were counted within 4 days of collection. Subsamples of needles from the branches sampled were analyzed for nutrient concentrations.

In the laboratory, three secondary branches were selected from each primary branch for needle retention counts. The secondary branches were divided into single-year growth increments, starting with the most recent growth and proceeding through the oldest segment for which needles were still present. Because the spruces were found to retain their needles for up to 30 years, only the first 5 years and two randomly selected, older needle age classes were sampled for each branch. This reduced the time required to count the needles while still providing an estimation of needle loss over the longer time frame. For each age class counted, measurements were made of twig length, number of needles present, and the number of needles absent as determined by the presence of residual needle scars. The fraction of needles remaining on the segment was then calculated for each segment by dividing needle number by the sum of the needle number and the number of residual needle scars. In the case of whitebark pine, fascicles and fascicle scars were counted.

Canopy Litterfall

The method used to determine litterfall rates was modified from Baker and others (1986). Twelve pairs of litter collection buckets were placed in each reference stand. The area of an individual bucket was 0.066 m^2 (0.72 ft^2). Material falling into the buckets was collected in nylon mesh liners. Three bucket pairs were placed randomly in each of four quadrants within each stand. One bucket pair in each trio was "fixed"; it always remained in the same location. The other two pairs were randomly relocated within the quadrant at the beginning of each sampling period. This fixed and movable bucket system allowed for the determination of both spatial and temporal variability of litterfall while minimizing the total number of buckets required (Reiley and others 1969). Bucket pairs were used to provide samples for the determination of both nitrogen/lignin ratio and trace element analysis (Baker and others 1986).

Litter bucket samples were collected three times each during the 1987 and 1988 field seasons. Samples were returned to the laboratory for processing. The samples were dried at 50 °C for 48 hours and weighed. Major components (needles, cones, fine branches) were separated. Each category was weighed separately and pooled for the season. These samples were analyzed for lignin and nitrogen concentration by methods described by Goering and Van Soest (1970) and Isaac and Johnson (1976), respectively.

Litter Decay Rates

Annual decay rates were determined for various species using litter bags (Crossley and Hoglund 1962; Singh and Gupta 1977). Litter from species indigenous to this study area was collected for this portion of the study just prior to abscission. These species included whitebark pine, Engelmann spruce, subalpine fir, and willow (*Salix* spp.). Leaves from Pacific dogwood (*Cornus nuttallii*) and needles from western white pine (*Pinus monticola*) were also used. These additional species were collected in Oregon, and were selected to provide a wider range of lignin and nitrogen concentrations.

Litter was weighed and placed in 20- by 20-cm polyester bags of 1-mm mesh size. Each bag contained approximately 10 g (dry weight) of litter. Subsamples of each species were used to determine moisture, lignin, and nitrogen content. The litter bags were placed in the field in August 1987 and were collected in August 1988. After collection, the remaining litter was removed from each bag, ovendried, and weighed. Litter loss was expressed as a rate constant (k), as well as a percentage (Jenny and others 1949; Olson 1963).

Elemental Analyses

In association with the 1987 needle retention study, needle samples were collected for elemental analysis from whitebark pine, Engelmann spruce, and subalpine fir. Litterfall samples collected during the 1987 and 1988 field seasons were also analyzed to determine concentrations of various elements. Litter bucket samples collected in June 1988, representing the overwinter accumulation of litter, were not used for elemental analysis due to the uncertainties associated with the effects of snowpack and other factors on the litter. Elemental analyses were performed by spark source emission spectroscopy (Alexander and McAnulty 1981).

RESULTS

Needle Retention

The results of the 1987 needle retention study are shown in figure 4. Data from both stands are combined because no significant difference was found between stands. Eighty percent of the whitebark pine needles observed were lost over a 12-year period. In contrast, Engelmann spruce retained over 75 percent of its needles during the same time frame, and did not reach the 50 percent loss level until the 14th year.

Chemical analysis indicated that both species had their highest nitrogen content in the needles of the current year (table 1). The nitrogen content of spruce needles was initially higher than that of the pine, but this difference decreased as needle age increased. All needle age classes of whitebark pine contained higher lignin content than corresponding age classes from Engelmann spruce.

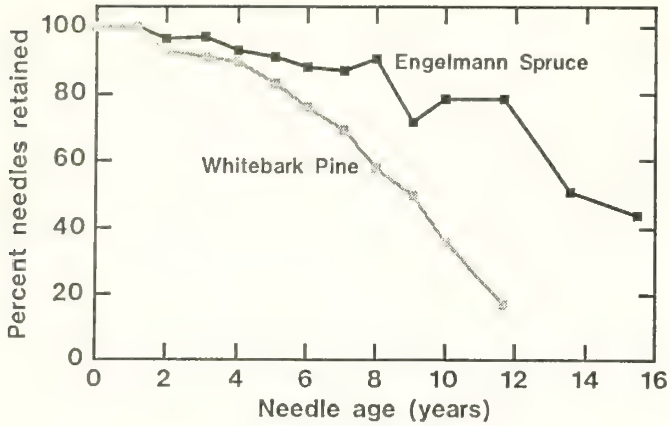

Figure 4—Needle retention for whitebark pine and Engelmann spruce, Nancy Lake, WY, 1987.

Canopy Litterfall

The 1987 and 1988 litterfall data for the two permanent stands are shown in table 2. These data indicate that the litterfall rates during 1988 were substantially higher than those of 1987. In both years, the total litterfall rate for BR-2 exceeded that of BR-1. In both stands, the dominant component of the litterfall was conifer needles.

Litter Decay

The initial nitrogen content of litter used ranged from 0.61 percent for whitebark pine to 1.18 percent for willow. Lignin is highest in the two pine species, and is lowest in the dogwood (table 3). Litter decomposition rate constants (k) were determined for each species by dividing the natural logarithm of the fraction of litter remaining by the time the litter remained in the field (years), and are shown in table 4. Of the species used in the study, decomposition of Pacific dogwood was the most rapid; the decomposition rate was slowest for western white pine.

Analysis of variance for the litter decay rates indicates that there were highly significant differences in decay rates between species, but not between stands (BR-1 and BR-2). The regression between the annual decay rate constants (k) determined for the six species used in this experiment and their respective lignin/nitrogen ratios was highly significant ($p < 0.001$):

$$k = 1.453(\text{lignin/nitrogen})^{-0.564}$$
$$r^2 = 0.93$$

The relationship between the decay constants and the lignin/nitrogen ratio of the species used for the Nancy Lake study site is shown in figure 5.

Table 1—Lignin and nitrogen content of conifer needles of seven different age classes, Nancy Lake, WY, 1987

	Whitebark pine		Engelmann spruce	
Needle age	N	Lignin	N	Lignin
Year	*Percent*			
<1	1.93	13	2.08	5
1	1.21	16	.74	10
2	1.30	17	.66	9
3	1.21	19	.66	9
6	1.06	12	.65	9
10	.84	14	.63	8
13	.92	13	([1])	([1])

[1]Insufficient sample volume for analysis.

Table 2—Litterfall data, Nancy Lake study site, 1987-1988

Collection date	Days in field	Total litter mass g/m² BR-1	BR-2	Seasonal litterfall rate g/ha day BR-1	BR-2
08/12/87	32	7.2	7.4		
09/16/87	35	3.5	10.7		
10/06/87	20	2.6	9.3		
Seasonal Total	87	13.3	27.4	1,500	3,150
07/18/88	19	13.9	12.4		
08/30/88	43	8.4	16.3		
Seasonal Total	62	22.3	28.7	3,600	4,630

Table 3—Initial lignin and nitrogen content of litter used in the determination of decay rates percent

	Lignin		Nitrogen		Lignin/N
Species	Mean	Stan. dev.	Mean	Stan. dev.	ratio
Pacific dogwood	6.2	0.20	0.87	0.20	7.1
Willow	21.4	1.51	1.18	.07	18.0
Engelmann spruce	13.4	.15	.74	.03	18.0
Subalpine fir	20.5	.70	.77	.05	26.0
Whitebark pine	23.4	2.02	.61	.02	38.0
Western white pine	27.0	3.48	.37	.01	73.0

Table 4—Decay constants for litter of six tree and shrub species, Nancy Lake, WY, 1988 (per year)

	Stand BR-1		Stand BR-2	
Species	Mean	Stan. dev.	Mean	Stan. dev.
Pacific dogwood	0.487	0.186	0.471	0.029
Willow	.284	.047	.266	.019
Engelmann spruce	.262	.038	.255	.020
Subalpine fir	.220	.023	.276	.035
Whitebark pine	.202	.032	.228	.047
Western white pine	.111	.019	.121	.019

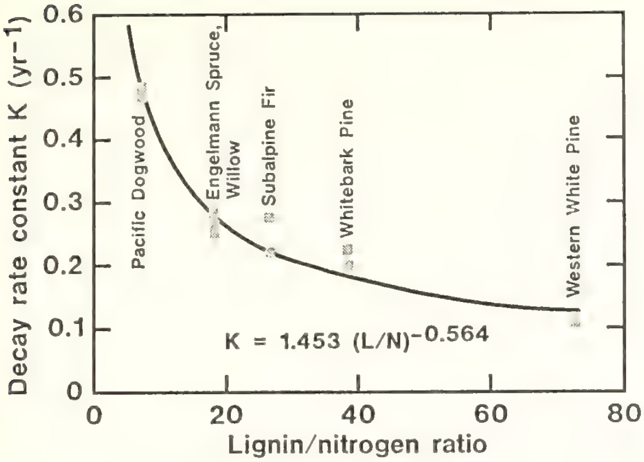

Figure 5—Relationship between decay rate constant and lignin/nitrogen ratio for six species, Nancy Lake, WY, 1987-88.

Elemental Analyses

Results of the analyses of litterfall samples and conifer needles for selected nutrients (P, K, Ca, and Mg) are shown in table 5.

DISCUSSION

The data collected during the 1987 and 1988 field seasons provide an indication of the recent status of these ecosystem processes at the Nancy Lake study site. Future measurements of these parameters can be compared with these baseline values to observe changes in the system. Additional data sets are required before we can adequately determine whether needle retention, canopy litterfall, and litter decomposition meet the five criteria described above for use as indicators of pollutant input.

Needle Retention

Needles of both whitebark pine and Engelmann spruce are retained for longer periods of time at this high-elevation system than are those of conifers observed in more temperate forests of the Pacific Northwest (Baker and others 1986). Many of the spruce examined at the Nancy Lake site retained needles for up to 30 years; this represents extremely long retention times for spruce needles (Harlow and Harrar 1958). We hypothesize that this extended retention rate represents a response to the shorter growing seasons or poor soil development characteristic of these high-elevation sites, where branch elongation and growth of new photosynthetic tissue are restricted. Preliminary data from a study designed to examine the relationship between needle retention rate and elevation in the Nancy Lake area seem to support the hypothesis (White and Wiersma, in preparation). The trees in the Nancy Lake area appear to have responded to the environmental conditions of the site by maintaining their needles for longer time periods. The older needles present do show signs of age or exposure to the harsh environmental stresses naturally present at the site (Bruns and others 1988).

Canopy Litterfall

Canopy litter input is a more difficult parameter to assess due to the limited collection period and to the problems associated with collecting accurate data during the winter months. These problems included damage to the collection buckets from snowpack and animals. The severe drought conditions prevalent in the area during 1988 may have resulted in annual litter input rates that were abnormally high for this area. Additional data are necessary to determine the extent of the natural variability associated with this parameter. The annual input rates determined for the two stands are extremely low compared with those of more temperate forest sites in the

Table 5—Concentrations of selected nutrients in conifer needles and litter samples, Nancy Lake, WY, 1987-1988 (all values in parts per million)

	Litterfall samples				
Collection date	**Stand**	**P**	**K**	**CA**	**MG**
August 1987	BR-1	2,800	2,830	4,790	972
	BR-2	2,460	2,410	2,990	1,330
September 1987	BR-1	1,530	2,900	5,160	835
	BR-2	1,270	1,680	3,450	1,330
October 1987	BR-1	1,160	2,120	5,920	769
	BR-2	989	1,690	6,280	1,110
July 1988	BR-1	2,560	2,440	7,200	961
	BR-2	1,600	1,970	6,180	1,260
August 1988	BR-1	1,890	2,250	11,800	685
	BR-2	1,450	1,750	8,365	1,220
	Conifer needles				
Collection date	**Species**	**P**	**K**	**CA**	**MG**
July 1987	Whitebark pine	1,710	2,180	7,600	1,420
July 1987	Engelmann spruce	1,240	2,580	15,400	767
July 1987	Subalpine fir	1,460	2,060	15,400	766

Pacific Northwest (Baker and others, in preparation; McShane and others 1983). This reflects the relatively low productivity expected in a forest with a limited growing season. The difference in litterfall rates found between the two stands can primarily be attributed to the presence of the many small firs in the understory of BR-2. Other possible contributing factors include differences in relative canopy cover, basal area factor, and the number of stems per acre between the two stands.

Litter Decomposition

Decomposition rates have been shown to be dependent on the initial ratio of the concentrations of lignin and nitrogen in the litter, with litter containing high relative concentrations of lignin expected to exhibit the slowest decomposition rates (Melillo and others 1982). This relationship was observed in the Nancy Lake decomposition data shown in figure 5. Decay rates, however, are also a function of climatic factors. The relationship between decay rates and lignin/nitrogen ratios from Nancy Lake is compared with those of other sites in figure 6. These sites represent a wide variety of climatic conditions, and include sites in Washington State (Harmon and others, in press), North Carolina (Cromack and Monk 1975), and Puerto Rico (La Caro and Rudd 1985). At any given lignin/nitrogen ratio, the decay rate constant is less at the Nancy Lake site than at other sites. This phenomenon appears to be due to a more harsh climate characteristic of the Wind River range.

Elemental Analyses

A cursory review of the nutrient concentration data from conifer needles and litter samples indicates that the levels of these nutrients in litter are similar in both stands (table 4). With respect to the needles, it

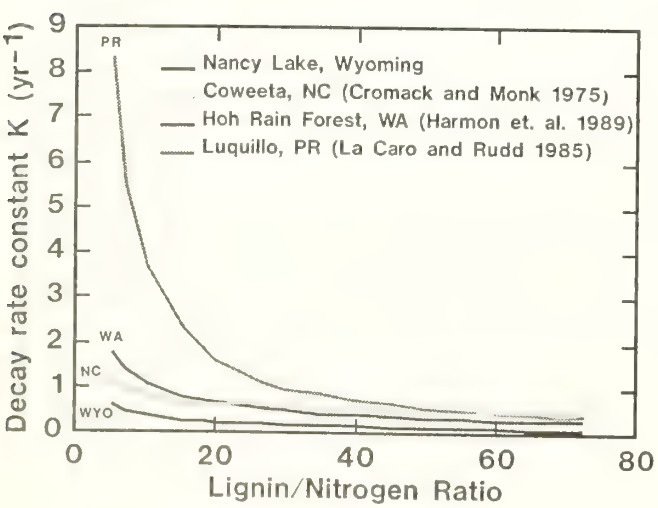

Figure 6—Comparison of relationship between decay rate constant and lignin/nitrogen ratio for sites of varying climatic conditions.

is interesting that whitebark pine needles were found to have only about half the calcium content of either Engelmann spruce or subalpine fir while possessing almost twice the concentration of magnesium. Comparison of the differences in calcium content of green needles versus that of litter collected during the same time frame (August 1987), indicates that a significant reabsorption of calcium from needles prior to abscission may be occurring. A more detailed review of the nutrient concentration data will be provided along with that of other chemical elements in these and other environmental media in a future report (Wiersma and others in preparation).

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STONE PINES AND BEARS

David J. Mattson
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ABSTRACT

Bears use stone pine (subsection Cembrae) seeds throughout the Northern Hemisphere, primarily Pinus sibirica, P. pumila, *and* P. koraiensis *in Eurasia, and* P. albicaulis *in North America. Bears make the greatest use of pine seeds in eastern Siberia and in the Northern Rocky Mountains of the United States. The pine seeds are important to bears because of their high nutritional value. During years of poor pine seed crops, Yellowstone area grizzly bears are trapped and killed more often; in Siberia, brown bears wander more and become more predatory.*

Grizzly use of pine seeds in the Yellowstone area is variable among years, in accord with the erratic seed production. Virtually all seeds used by bears are extracted from red squirrel caches. In many areas, the whitebark pine has nearly disappeared as a result of the double onslaught by white pine blister rust and mountain pine beetle infestations. This important food for some bears and populations has been nearly eliminated, and may not be available to bears despite human intervention for hundreds of years. Because the trees are so thinly distributed, silvicultural treatments hold little promise of appreciably enhancing pine seed availability to bears.

INTRODUCTION

The seeds of whitebark pine (*Pinus albicaulis*) and other stone pines (subsection Cembrae) are a high-quality wildlife food characterized by high triacerglycerol content (Craighead and others 1982; Hutchins and Lanner 1982; Mealey 1980; Shcherbina and Larionova 1963) and energy concentration comparable to that of fleshy fruits (Craighead and others 1982; Mealey 1980). Large seed size contributes to efficiencies of use by numerous species of birds and mammals (Hutchins and Lanner 1982; Tomback 1983). Because the cones are typically indehiscent (Arno and Hoff 1989; Lanner 1982), seeds remain concentrated in the cones and contribute to efficiencies of use, especially by red squirrels (*Tamiasciurus hudsonicus*) and bears (*Ursus* spp.). Where bears eat the entire cone, the fleshy pulp of the cone also contributes to their diet (Jonkel 1967).

Whitebark pine and other stone pine seeds are high-quality bear food for reasons in addition to their high energy content. Stone pine seeds mature by August and are available from then until bears hibernate (Hutchins and Lanner 1982; Iroshnikov 1963; Kendall 1983). This period corresponds with the critical hyperphaegic state during which bears accumulate the fat necessary to sustain them through hibernation and subsequent hypophaegia (Nelson and others 1983). Because of their high digestible lipid content, pine seeds very likely contribute more to efficiencies of body fat accumulation by bears than foods high in protein or sugar content (Allen 1976; Brody and Pelton 1988; Hadley 1985). Because of their durable nature, pine seeds can overwinter in or out of cones and provide high-quality food for bears the next spring and summer. Whitebark pine seeds and cones also contain estrogenic compounds (Jonkel 1967; Jonkel and Cowan 1971). These compounds could influence reproduction in bears, but effects are undocumented and the precise roles played by estrogens in delayed implantation are as yet unknown.

Bear use of stone pines is disadvantaged by frequent poor cone crops. Craighead and Mitchell (1982) recorded bumper cone crops of whitebark pine only 2 of 12 years in the Yellowstone National Park area and 2 of 7 years in the Scapegoat Mountains of Montana. In recent years we recorded good crops 2 and poor crops 4 out of 12 years in the Yellowstone area. Data from Weaver and Forcella (1986) suggested an average 2-year interval between poor crops and 6-year interval between good crops of whitebark pine in the Rocky Mountains during the 1970's. In Siberia, Nesvetailo (1987) estimated 10 good and 10 poor Siberian stone pine crops during a 58-year period. Together these observations suggest an average 2- to 6-year interval between both good and poor stone pine crops. It is also clear that this cycle is highly irregular among years, regions, and habitat types.

In areas where bears depend on stone pine seeds for fattening, and where there are typically few fleshy fruits available, years of poor pine seed crops result in increased conflict between bears and humans. In the Yellowstone area there is a predictable and dramatic increase in adult female bear deaths and management actions against bears during poor seed crop years (Blanchard, this proceedings). Similarly, in Siberia poor stone pine seed crops result in increased attacks on humans and increased livestock and agricultural crop depredations (Stroganov 1962; Ustinov 1965). This increased conflict probably results not only from an increased number of poor-condition bears (Ustinov 1965), but also because of the many human foods available in bear habitat that constitute high-quality alternatives to native fruit and seed crops (Mattson, in press).

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DISTRIBUTION OF USE

In common with other stone pines (including *P. sibirica, P. pumila,* and *P. koriaensis*), whitebark pine is used by bears wherever it is abundant (fig. 1). In North America this occurs south of the Canadian border in the cordillera of the western United States. Farther north, whitebark pine is only an incidental part of the forest vegetation (Arno and Hoff 1989).

Within the range of stone pines, bear use of stone pine seeds ranged from near zero in Glacier National Park, MT, (Kendall 1986) and the Mission Mountains of Montana (Mace and Jonkel 1986) to 18.3 percent and 28 percent of total sampled fecal volume in Yellowstone (Mattson and others, in preparation) and the Lake Baikal area of Ulan-Ude, U.S.S.R. (Ustinov 1965; Vereschagin 1976), respectively (table 1). Peak use consistently occurred from September through November. A secondary peak usually occurred in the spring, in association with use of overwintered pine seeds following large crops the previous fall. This pattern of use is typified by Yellowstone data for the years 1977-87 (fig. 2). When feeding on pine seeds, bears tend to consume the seeds to the near-exclusion of all other foods. This was consistently reflected in high mean percent volumes of pine seeds in scats—percent volume divided by percent frequency (fig. 2).

There is a remarkable correspondence between the current southern limit of the main distribution of brown bears (*Ursus arctos*) and stone pines (fig. 1). This correspondence almost certainly does not reflect dependence of either species on the other. More likely human (*Homo sapiens*) intolerance has relegated brown bears to the comparatively inhospitable and harsh environments characterized by stone pines (Mattson, in press). Nonetheless, within this area of overlap, stone pine seeds are an important food for numerous Asian and North American bear populations (Aune and Kasworm, in press; Bergman 1936; Bromlei 1965; Craighead and others 1982; Kendall 1983; Kistchinski 1972; Novikov 1956; Stroganov 1962; Ustinov 1965, 1976; and others), especially where there were few, irregularly available fleshy fruits (Mattson and others, in preparation).

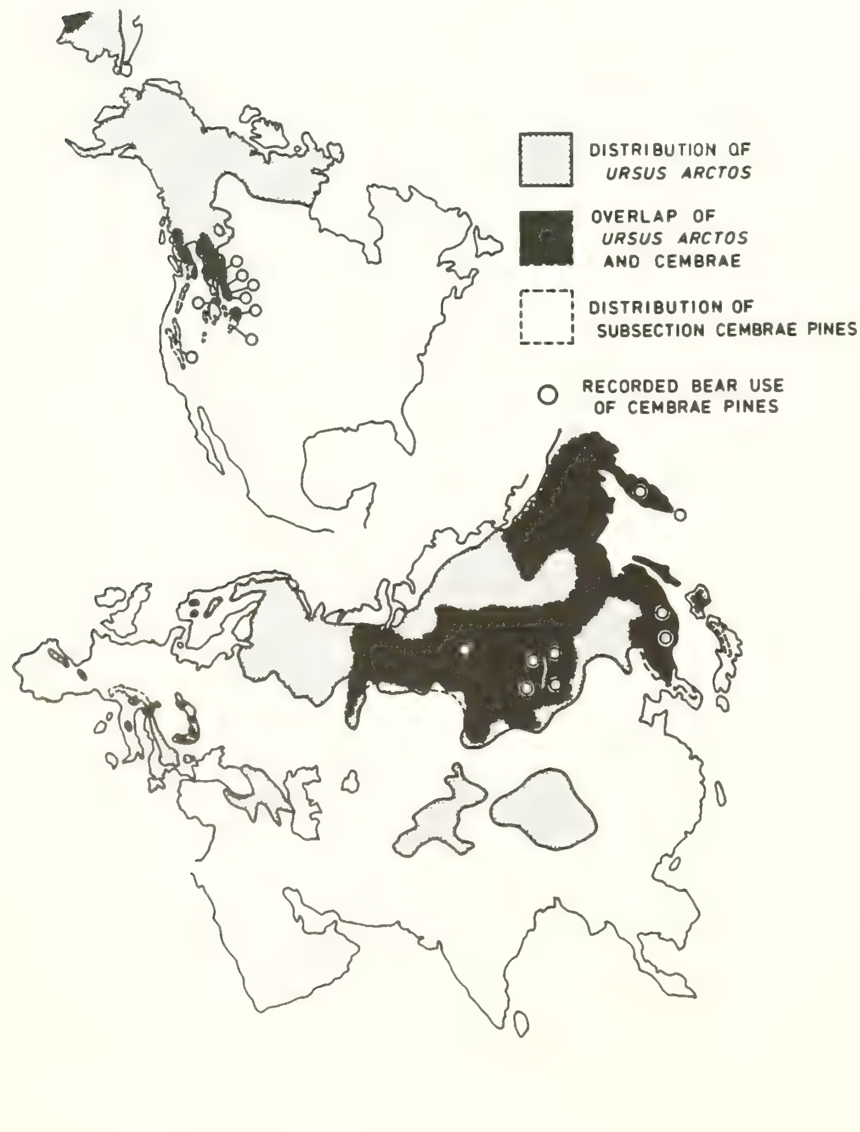

Figure 1—Distribution of brown bears (*Ursus arctos*) and stone pines (subsection Cembrae), and recorded instances of substantial stone pine seed use by bears (*Ursus* spp.) (Clevenger and others 1987; Critchfield and Little 1966; Elgmork 1987; Patnode and LeFranc 1987; Yi-Ching 1981; Zunino 1975).

Table 1—Percent frequency (%F) and volume (%V) of stone pine seeds in bear scats from study areas in the Rocky Mountains, Sierra Nevada, and Siberia

Study area	Total scat collection %F	Total scat collection %V	Maximum month or season %F	Maximum month or season %V	Month or season
Rocky Mountains					
Glacier NP, BC[1]	—	—	2	tr	Fall
North Fork of the Flathead, MT[2/11]	4.0	1.2	19.2	11.3	September
South Fork of the Flathead, MT[2]	.7	.4	—	—	
Glacier NP, MT[3]	0	0	—	—	
Mission Mtns, MT[2]	.3	.1	—	—	
East Front, MT[2/4]	14.6/5.1	12.6/4.5	33.3	31.0	October
Yellowstone, MT&WY[5]	30.3	18.4	42.8	39.2	October
Grays River Mtns, WY[6]	—	—	22.5	15.0	Fall
Sierra Nevada					
Yosemite NP, CA[7]	3	1	17	7	Fall
Siberia					
Kamchatka[8]	—	14	—	—	
Primore[8]	—	6	—	—	
Ussuri[9]	—	5.3	—	25.0	November
Baikal[8/10]	—	28	—	100.0	October

[1]Mundy (1963).
[2]Mace and Jonkel (1983).
[3]Kendall (1986).
[4]Aune and Kasworm (in press).
[5]Mattson and others (in preparation).
[6]Irwin and Hammond (1985).
[7]Graber and White (1983).
[8]Vereschagin (1976).
[9]Bromlei (1965).
[10]Ustinov (1965).
[11]Husby and others (1977).

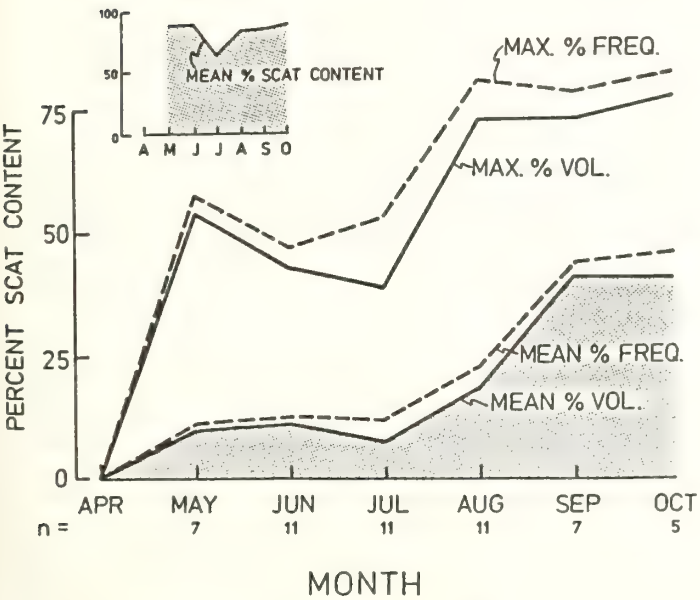

Figure 2—Percent frequency and volume of whitebark pine seeds in scats collected in the Yellowstone area, by month, 1977-87 (*n* = number of years). Inset diagram depicts mean percent pine seed volume in scats of occurrence, by month.

ACQUISITION OF PINE SEEDS

Bears employ several strategies to acquire stone pine seeds depending on the presence of rodent intermediaries, the density and stature of stone pine forests, and the bear's ability to climb. Black bears (*Ursus americanus* and *Selenarctos thibetanus*) are more adept climbers than brown bears (Herrero 1978) and are more likely to climb trees to consume seeds in the canopy, or to break limbs off and subsequently consume the seeds on the forest floor (Barnes and Bray 1967; Bromlei 1965; Mealey 1975; Stroganov 1962). In northwestern Montana, bears commonly climbed trees to acquire whitebark pine cones. These bears often had no hair on their entire front legs after a fall spent feeding on pine seeds (figs. 3 and 4). Pitch that built up on the feet and legs from clawing small whitebark pine trees peeled off when caked with dirt and debris, taking all the hair along.

Brown bears seem generally restricted to acquiring seeds that have fallen or been brought down to the forest floor by other animals. Scavenging on fallen cones is apparently common in Siberia (Bromlei 1965). In the Rocky Mountains, forest floor scavenging on cones is rare (Mattson, personal observation; Aune and Kasworm, in press). In the Yellowstone area only 3 percent of 193 instances where bears were known to have used pine seeds involved scavenging on fallen cones. These few

Figure 3—The front feet of this black bear are caked with pitch from feeding on whitebark pine cones and seeds (1959 photo by C. Jonkel).

Figure 4—Cracking of the pitch, debris, and hair mat on this young black bear's front foot show the extent of whitebark pine cone and seed feeding by this bear, and the process whereby bears lost the hair from their front legs (1959 photo by C. Jonkel).

instances occurred in stands where whitebark pine comprised approximately 76 percent of total stand basal area ($\bar{X}$= 46.7 ± 10.6 m^2/ha), and following extreme weather that knocked cones out of the trees. Taylor (1964) similarly mentioned bears concentrating at and scavenging on cones on the forest floor in an area where whitebark pine cones were wind-thrown by a "violent storm." Bears also consumed cones directly from the canopy of dwarfed stone pines, commonly in Kamchatka (Bergman 1936; Kistchinski 1972) and less frequently near timberline in northwest Montana and Yellowstone (Mattson and Jonkel, personal observation; Craighead and others 1982; Jonkel 1967; Tisch 1961).

In most areas where brown bears make substantial use of stone pine seeds, rodents are a critical link. In the Rocky Mountains red squirrels preferentially harvest whitebark and limber pine seeds (Hutchins and Lanner 1982) and cache them in middens, typically in intact cones (Hutchins and Lanner 1982; Kendall 1983). Bears subsequently search out these middens and excavate the whitebark pine cones. This commonly occurs in the Yellowstone area (Kendall 1983) and along the East Front of the Rocky Mountains in Montana (Aune and Kasworm, in press; Schallenberger and Jonkel 1980). Excavation of squirrel middens by bears to obtain seed and fruits is also known from northern Idaho (whitebark pine seeds) (Kendall 1989), Yosemite National Park (whitebark pine seeds) (Graber and White 1983), and northern Minnesota (hazelnuts [*Corylus cornuta*]) (Rogers 1989). In the Yellowstone area, 97 percent of 196 pine seed feeding sites involved excavation of squirrel middens. A similar high percentage of squirrel midden use was characteristic on the East Front of Montana (Aune and Kasworm, in preparation; Schallenberger and Jonkel 1980).

In Siberia, the Siberian chipmunk (*Eutamias sibiricus*) appears to be the primary rodent intermediary between stone pine seeds and bears. As in North America, stone pine seeds are a preferred food of both chipmunks and squirrels (*Sciurus vulgaris*) in Siberia (Ognev 1940). Siberian chipmunks commonly make stone pine seed caches of 1.5 to 2 kg in size (up to 6 kg) for winter and spring consumption (Ognev 1940). And as in the Rocky Mountains, bears search out and excavate these rodent caches in spring and late fall (Bromlei 1965; Novikov 1956; Ognev 1940; Stroganov 1962; Ustinov 1976).

The much greater use of chipmunk rather than squirrel caches by Siberian bears is puzzling. In his monograph on Eurasian mammals, Ognev (1940) suggested that chipmunks commonly attained much higher densities than squirrels in the range of Siberian stone pines. He quoted an estimate for one area of only 0.14 squirrel "nests"/km of transects. This compared with 0.11 to 0.14 squirrel middens/km in pure whitebark pine stands of the Yellowstone area (Reinhart and Mattson, this proceedings). Significantly, virtually no bear use of squirrel middens was observed in pure whitebark pine stands of the Yellowstone area. This suggests that when squirrels are at such low densities bears use relatively few squirrel caches. By all indications Siberian squirrels more often cache cones in hollow trees, through elevated openings, than do squirrels in the Rocky Mountains. This would further complicate acquisition of squirrel caches by Siberian bears.

Bears are remarkably adept at extracting seeds from cones in the Yellowstone area; few cone remnants are ingested along with the seeds (Kendall 1983). One way that bears achieve this is by scraping away the cone scales with their claws and lapping up the seeds with their tongues from among the debris (Kendall 1983). Typical bear feces that result from consumption of pine seeds consist almost wholly of broken seed coats (Kendall 1983; Tisch 1961). Very few seeds pass through intact,

and it is doubtful that bears serve as a significant dispersal agent for whitebark pine in most of the Rocky Mountains (Hutchins and Lanner 1982). This is especially likely given the poor germination potential of unburied whitebark pine seeds (McCaughey, this proceedings).

Interestingly, Siberian brown bears are apparently prone to ingest more cone scales when scavenging pine seeds out of cones from the forest floor (Semechkin 1963). This may be a consequence of their greater use of individual seeds extracted from chipmunk caches. The scavenging of cones may also be marginally profitable, providing little incentive to invest the added time and energy required to break apart the cones and pick out the individual seeds.

Of the three main seed-acquiring techniques, the excavation of rodent caches is on average the most energetically efficient process for bears. Unless there is a bumper crop, bears will expend considerably more energy than they acquire by breaking major tree limbs and harvesting seeds from the relatively few cones on each limb. Similarly, unless there is an unusual weather event, very few cones will survive depredations of chipmunks, nutcrackers (*Nucifraga* spp.), and other avifauna and fall intact to the forest floor (Hutchins and Lanner 1982; Kozhevnikov 1963). Rodents increase the foraging efficiencies for bears by harvesting otherwise unavailable, intact cones and seeds from trees, then concentrating them in caches. Red squirrels will use caching sites or middens for many years (Reinhart and Mattson, this proceedings), which in turn facilitates their location by bears. In the Yellowstone area individual middens receive repeat use by bears in the same and different years (Mattson, personal observation; Kendall 1983). Bear depredations may be so heavy in some habitats that many squirrels may not survive (Mattson and Reinhart 1987; Reinhart and Mattson, this proceedings). In these situations midden locations may be less predictable due to higher turnover of individuals in the squirrel population.

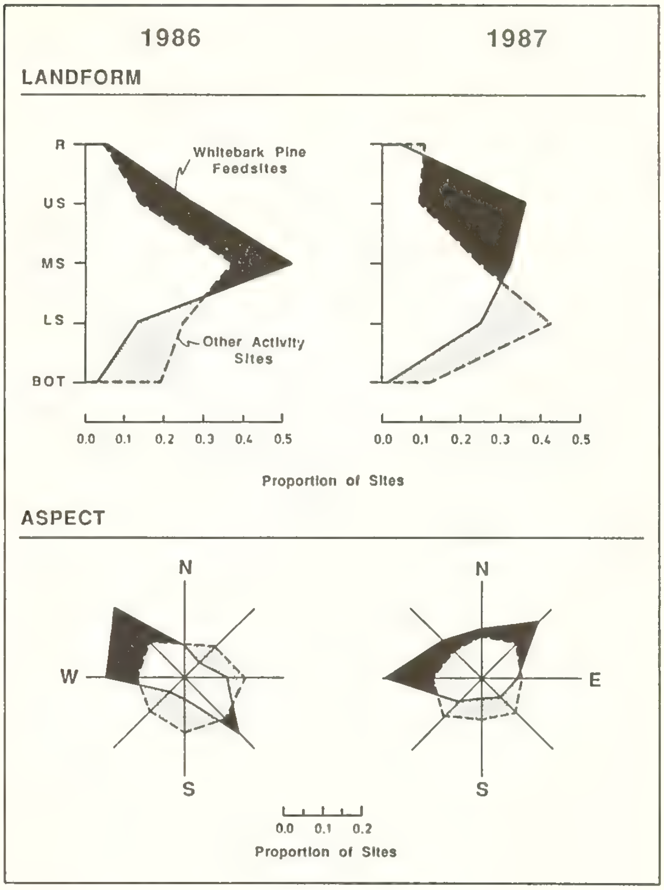

Figure 5—Proportionate distribution of whitebark pine seed feed sites and all other activity sites among landform and aspect classes in the Yellowstone area.

CHARACTERISTICS OF PINE SEED FEEDING SITES

Topography

Bears exhibited different tendencies in their use of the landscape to acquire pine seeds depending on the year and study area. In the Yellowstone area, bears used mid-slopes and up-slopes to forage on pine seeds more than expected from distribution of all activity sites (fig. 5). However, they exhibited greater preference for mid-slopes during 1986, when using an overwintered crop, and up-slopes during 1987, when using a current year's crop. (Activity site and feed-site parameters were determined from visiting telemetry locations of radio-instrumented bears.) Greater use of mid- and up-slopes corresponded with the tendency for whitebark pine to occur at higher elevations in more wind-exposed habitats (Mattson and Reinhart, this proceedings). Interestingly, in the Yellowstone area bears used ridgetops relatively little for pine seed foraging; in past years, ridgetops were the main foraging area for bears in the Whitefish Range of northwestern Montana (Jonkel 1967).

Distribution of pine seed feed sites among aspects varied considerably among years, regions, and landforms. In the Yellowstone area, greater than expected use of west and northwest exposures occurred during 1986, and of west, northwest, and northeast exposures during 1987 (fig. 5). Use of west exposures occurred most often on mid- and low slopes. On the East Front of the Rockies, northeast, east-southeast, southwest, and west-southwest exposures were used most for foraging on pine seeds (Aune and Kasworm, in press).

The distribution of use among aspects in Yellowstone appeared to be related to environmental factors, depending on landform. (We derived estimates for environmental variables from published data.) Use of up-slopes and ridges was negatively related to estimated summer radiation (Buffo and others 1972) and estimated relative frequency of summer winds >8 k/h (Dirks and Martner 1982, Upper Rendezvous site) (fig. 6). This suggests that more exposed and "droughty" conditions did not favor bear use of pine seeds in convex topography. This effect was most likely mediated through the abundance of red squirrels; site favorability for squirrels was negatively

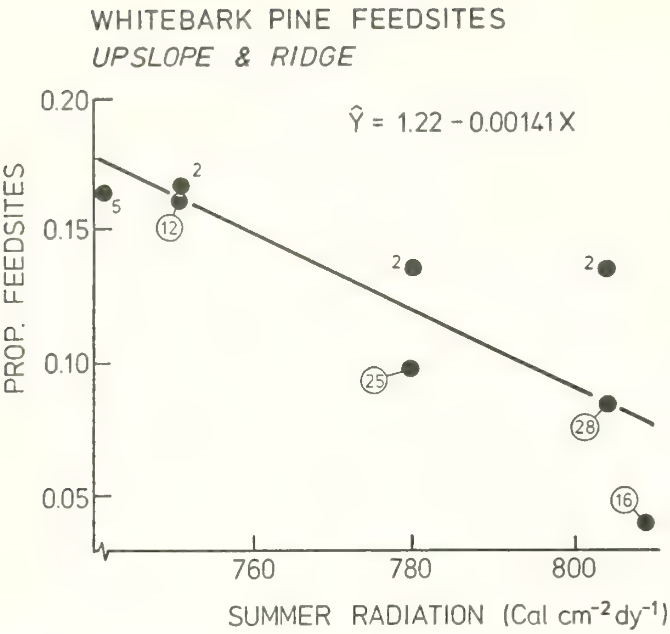

Figure 6—Relationship of proportionate pine seed feed-site distribution in Yellowstone among aspect classes, on convex landforms relative to summer radiation (June 22) and frequency of summer winds >8 k/h (numbers, with higher values circled).

related to wind exposure and positively related to stand basal area (Reinhart and Mattson, this proceedings). On mid- and low slopes, pine seed foraging increased exponentially with increased frequency of winter winds >8 k/h ($\hat{y} = 0.097 + 12.2\,x^4$, where y is the proportion of pine seed feed sites and x is the proportion of winter winds >8 k/h, in a given aspect class). This relationship was probably related to decreased or more irregularly drifted winter snowpack with increased winter wind exposure (Reinhart and Mattson, this proceedings). Given that spring and summer bear use of overwintered crops occurred more commonly on mid-slopes, a combination of shallower snowpack and more productive squirrel habitat probably favored early season bear use of overwintered squirrel caches on west slopes.

The elevational distribution of pine seed feed sites also varied among study areas and years, although in Yellowstone virtually all feed sites occurred above 2,425 m (8,000 ft) elevation (fig. 7). East Front feed sites averaged 455 m (1,500 ft) lower in elevation than Yellowstone feed sites, and partly reflected the 3° latitude difference in study areas (Aune and Kasworm, in press). The elevational distribution of pine seed feed sites was also much more dispersed on the East Front compared with Yellowstone. The much lower elevational range of East Front feed sites, between 1,515 and 1,879 m (5,000 and 6,200 ft), almost certainly reflected bear use of limber pine (*Pinus flexilis*) seeds. Bear use of limber pine seeds from squirrel caches was also recorded in Yellowstone, but only three times out of a total of 196 recorded instances of pine seed use.

Use of the overwintered Yellowstone pine seed crop during 1986 tended to occur at higher elevations than use of the current year's crops during 1979 and 1987 (fig. 7). The higher elevational distribution of feed sites during 1986 conformed more closely to the elevational distribution of whitebark pine (from the Mount Washburn massif; see Mattson and Reinhart, this proceedings) than did pine seed feed sites the other 2 years. This suggests that bears preferred stands with higher whitebark pine basal area when using overwintered seed crops.

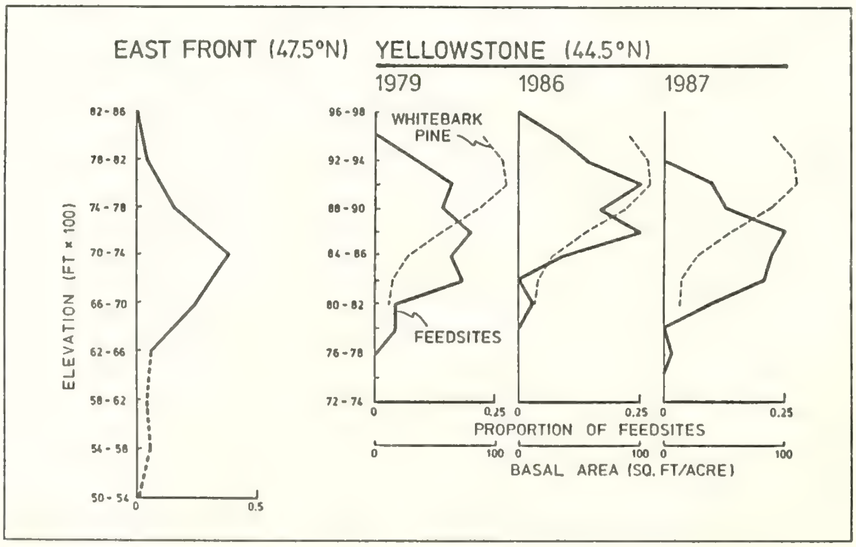

Figure 7—Proportionate distribution of East Front (Aune and Kasworm, in press) and Yellowstone (by year) pine seed feed sites by elevation, and mean whitebark pine basal area by elevation for the Yellowstone area (1 m = 3.28 ft; 1 m^2/ha = 0.2295 ft^2/acre).

Timber Overstory

There was a weak positive association between intensity of midden use by bears and whitebark pine basal area (table 2). This was more evident during use of an over-wintered crop during 1986, when bears tended to use more stands with higher whitebark pine basal areas compared to 1987 (x^2 = 12.81, df = 5, P = 0.025; number of feed sites relative to six categories based on whitebark pine basal area). This difference is understandable given that stands with higher whitebark pine basal areas would have a higher probability of providing over-wintered seeds. However, there was very little correlation between number of cones excavated from middens by bears and whitebark pine basal area (r = 0.194, n = 69, P = 0.106).

Whitebark pine basal area was apparently only one of several habitat parameters that determined the location and intensity of pine seed foraging by bears. This was further implied by the relatively low average basal areas and percent composition of whitebark pine in stands used by bears for foraging on pine seeds (table 3). Stands with high percent whitebark pine composition and whitebark pine basal area were generally not preferentially selected by bears in the Yellowstone area.

We recorded no use of younger aged, early successional stands by bears for foraging on whitebark pine seeds in the Yellowstone area. All stands used by bears were classified as mature to overmature and mid-successional to climax. This is not surprising, given the probable late age at which whitebark pine produce an appreciable number of cones under normal stand conditions. Although the relationship between cone production and stand age is not known for whitebark pine, this relationship is well described for the related and morphologically similar Siberian stone pine (Axelrod 1986). Generally, Siberian stone pines do not produce appreciable numbers of cones until stands reach 90 to 120 years of age. Under exceptional conditions appreciable cone production begins as early as 30 years and, depending on stand and site conditions, high levels of cone production last 150 to 300 years (Iroshnikov and others 1963; Kozhevnikov 1963). It is reasonable, therefore, to assume that most habitat types used by bears for foraging on whitebark pine seeds do not produce sufficient numbers of seeds to sustain bear use until stands reach approximately 100 ± 20 years of age.

Table 2—Whitebark pine basal area associated with different intensities of midden use by bears in the Yellowstone area, 1986 and 1987

	Intensity of use								
	Low			Moderate			High		
Year	n	$\bar{X}$	S_x	n	$\bar{X}$	S_x	n	$\bar{X}$	S_x
1986	5	10.1	5.0	15	13.8	17.1	14	19.0	27.1
1987	14	9.1	7.8	20	15.8	15.4	19	14.0	15.7

Habitat Types

The majority of pine seed use by bears in the Yellowstone and East Front study areas occurred in the ABLA/VASC-PIAL h.t. phase (table 4). (This same type was designated the ABLA-PIAL/VASC h.t. in the East Front study area; see Appendix A for habitat type nomenclature). Proportionate use of the ABLA/VASC-PIAL phase in the Yellowstone area varied from year to year, primarily as a result of different levels of use in mesic mid-elevation and drier high-elevation habitat types. The proportionate distribution of pine seed feed sites among all habitat types in the East Front and in Yellowstone during 1987 was remarkably similar. Very little use of the PIAL series was documented in both study areas. These observations suggest that bear foraging on pine seeds in the various drier portions of the Rocky Mountains occurs in similar habitats for probably much the same reasons.

We quantified bear use of different habitat types by two different use-density indices for the Yellowstone area (table 5). These calculations used data collected at bear feed sites in 1986 and 1987. The estimated density of excavated material (D x E) indexed the density of bear use in sites selected for use by bears. (A/F) x E was dimensionless and quantified overall density of bear feeding on pine seeds in a given type within the whitebark pine zone (>2,545 m); it was not specific to sites selected by bears. The second index was not calculated for high-elevation, dry habitat types because we lacked an estimate of availability for this type.

Values of the second index suggest that overall density of pine seed feeding by bears at elevations >2,545 m (the whitebark pine zone) was highest in lodgepole pine (LP) cover types of the ABLA/VASC-PIAL phase and lowest in the ABLA/VAGL-VASC and ABLA/VASC-VASC phases. Intermediate levels of use characterized whitebark pine (WB) cover types of the ABLA/VASC-PIAL phase and the ABLA/THOC and ABLA/CACA h.t.'s.

Table 3—Whitebark pine and total stand basal area ($\bar{X} \pm S_x$), and whitebark pine as a percent of total stand basal area and cover for whitebark pine seed feed sites in the Yellowstone area, 1986 and 1987

	Basal area (m²/ha)				Mean percent	Percent whitebark pine canopy cover	
	Total		Whitebark pine		whitebark		
Year	$\bar{X}$	S_x	$\bar{X}$	S_x	pine	$\bar{X}$	S_x
1986	49.4	22.3	14.9	20.5	30.2	—	—
1987	46.6	23.0	12.9	15.1	27.8	33.3	13.7

The degree to which bears were selecting specific sites to feed on pine seeds within a habitat type is suggested by the ratio of estimated midden use density at bear-selected sites to the ratio of observed to expected proportionate use (D/(A/F)). A high value suggests that although relatively few sites were used by bears within a type, those few sites received relatively high-density use because of favorable combinations of squirrel densities and whitebark pine basal area. This was especially true for the ABLA/CACA h.t., and to a lesser extent for the ABLA/VAGL-VASC and ABLA/VASC-VASC phases and spruce-fir (SF) cover types of the ABLA/VASC-PIAL phase. In other habitat types bear use of pine seeds was more uniform.

Bears used the ABLA/VASC-PIAL phase and high-elevation dry types (ABLA/ARCO and ABLA/RIMO h.t.'s) during 1986 and 1987 primarily to feed on pine seeds (fig. 8). Very little bear activity in the whitebark pine (PIAL) series was devoted to use of pine seeds, principally because very few squirrels reside in this type (Reinhart and Mattson, this proceedings); most bear activity in the PIAL series was described as travel. This assessment emphasizes the importance of the ABLA/VASC-PIAL phase and, in areas where this phase is less common, the drier high-elevation *Abies lasiocarpa* (ABLA) series types.

The ratio of whitebark pine basal area at sites used to forage on pine nuts and whitebark pine basal area at all other activity sites within a given habitat type is shown in figure 8. These data indicate that bears selected pine seed feed sites in the ABLA/VASC-VASC phase and ABLA/ THOC h.t. principally on the basis of locally greater whitebark pine basal area; use of these types for pine seed foraging was restricted to anomalous sites at higher elevations where mature whitebark pine occurred in appreciable amounts.

Table 4—Proportional use (P) of habitat types and habitat type groups by bears for foraging on whitebark pine seeds in the Yellowstone area and East Front of the Rockies (data from Aune and Kasworm, in press)

	Yellowstone							
	1979		1986		1987		East Front	
Habitat types	P	*n*	P	*n*	P	*n*	P	*n*
ABLA/VASC-PIAL ABLA-PIAL/VASC	0.700	35	0.583	21	0.534	39	0.522	35
High-elevation, subxeric	.120	6	.250	9	.082	6	.104	7
Mesic-subhydric, mid-elev.	.180	9	.194	7	.315	23	.313	21
Mid-lower elev., subxeric	.000	0	.000	0	.068	5	.060	4
Total *n* =		50		36		73		67

Table 5—Whitebark pine basal area, estimated squirrel densities, and parameters of bear use for whitebark pine feed sites in habitat types of the whitebark pine zone

Habitat types	(A) *n*	(B) Estimated squirrel density (*n*/km)	(C) Whitebark pine basal area m²/ha $\bar{X}$	S_x	(D) Estimated density of midden use (*n*/km)	(E) Excavated material (*m*³/midden) $\bar{X}$	S_x	(D x E) Estimated density of excavated material (*m*³/km)	(F) Expected frequency[1]	(A/F) Ratio, observed/ expected	(A/F x E) Density of excavated material (dimensionless)	D/(A/F)
ABLA/VASC-PIAL LP cover types	14	2.76	4.3	5.8	1.24	6.6	4.0	8.18	6.7	2.09	13.8	0.59
ABLA/VASC-PIAL WB cover types	37	2.05	20.1	17.0	1.59	5.6	6.9	8.86	27.5	1.34	7.5	1.18
ABLA/VASC-PIAL SF cover types	6	2.36	10.7	9.0	1.43	3.5	3.8	5.00	7.8	.77	2.9	1.86
High elev., dry[2]	13	.85	14.9	25.0	.58	7.0	8.0	4.06	—	—	—	—
Low elev., dry[3]	5	2.23	9.2	9.7	1.25	1.8	—	2.25	4.1	1.22	2.2	1.02
ABLA/CACA	4	3.62	9.2	15.4	2.07	7.4	—	15.32	6.7	.60	4.4	3.45
ABLA/THOC	19	2.62	10.2	11.5	1.56	5.3	5.1	8.21	18.2	1.04	5.5	1.50
ABLA/VAGL-VASC	4	1.32	5.7	6.9	.65	2.8	—	1.82	11.7	.34	1.0	1.91
ABLA/VASC-VASC	5	2.92	.9	2.0	1.00	2.3	3.9	2.30	9.9	.50	1.2	2.00
PIAL series	6	.14	40.2	4.4	.14	2.4	—	.34	7.3	.82	2.0	.17

[1]From Mount Washburn study area, Yellowstone National Park (*n* = 835).
[2]ABLA/ARCO, ABLA/RIMO h.t.'s.
[3]ABLA/SPBE, ABLA/JUCO, and ABLA/BERE h.t.'s.

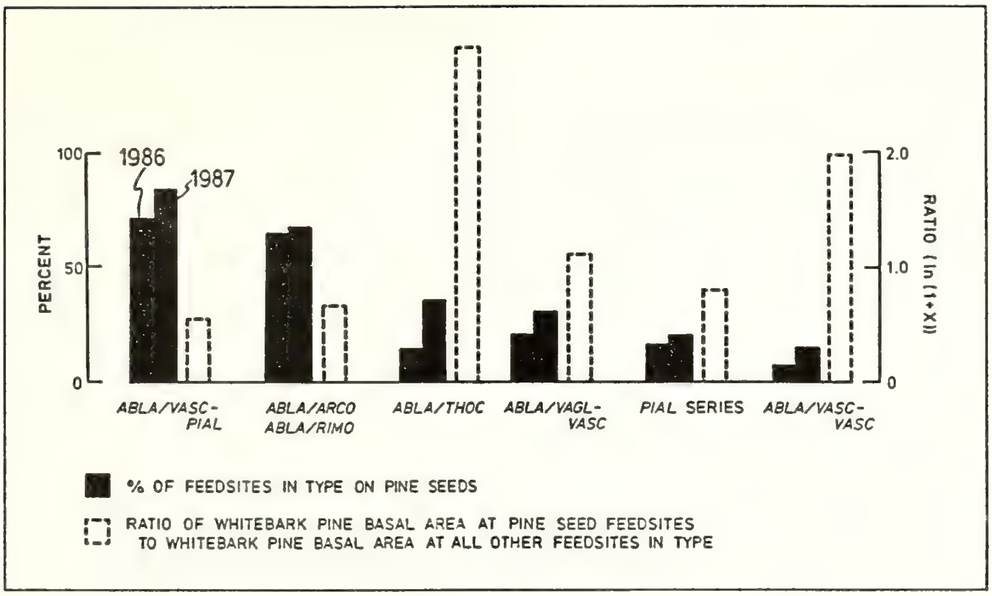

Figure 8—Percent of activity sites devoted to pine seed use in Yellowstone habitat types, for 1986 and 1987, and the ratio (ln (1 + *X*)) of whitebark pine basal area at pine seed feed sites to whitebark pine basal area at all other activity sites for 1986 and 1987 combined (1986, $n = 36$; 1987, $n = 73$ pine seed feed sites).

USE OF SQUIRREL MIDDENS

Most bear use of pine seeds in the Yellowstone area was from cones cached in squirrel middens. A major portion of bear excavations in middens were <2.0 m^3 in size, and could be characterized as incidental or exploratory (fig. 9). A few midden excavations ($n = 3$) were extensive (30 to 51 m^3). The number of cones excavated by bears per midden ($\hat{y}$) during 1987 was positively and significantly related to total excavated volume (x) ($\hat{y} = 33.2 + 13.6x$; $r^2 = 0.676$, $n = 52$, $F = 219.8$, $P < 0.000$); excavated volume reflected the relative number of seeds acquired by bears from a midden. The volume of excavated material did not vary significantly among middens from different habitat types.

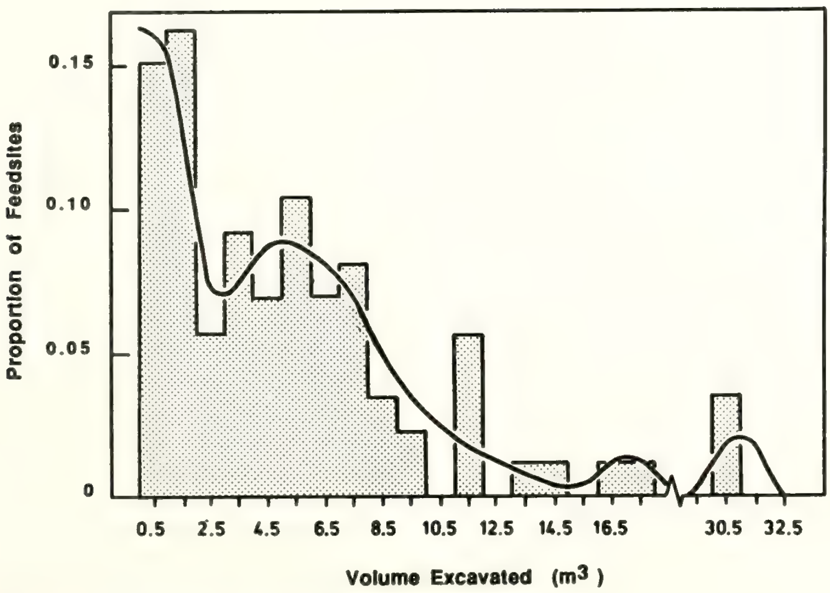

Figure 9—Proportionate distribution of Yellowstone pine seed feed sites, for 1986 and 1987 combined, with respect to estimated excavated volume ($n = 109$).

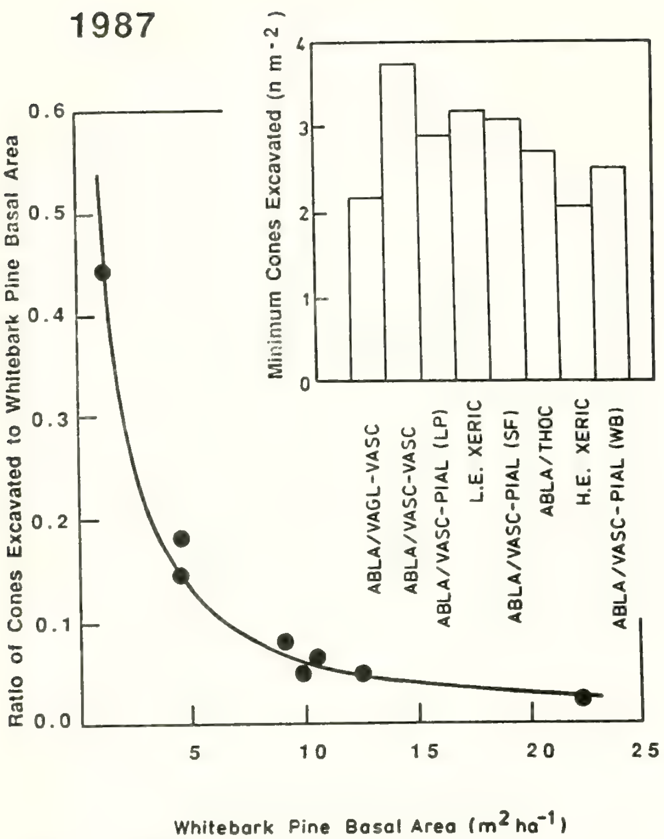

Figure 10—Relationship of the ratio of excavated cone density to whitebark pine basal area averaged for Yellowstone area habitat types, for 1987. Inset depicts mean estimated number of cones excavated/m^2 for Yellowstone area habitat types.

The apparent preferential harvest of whitebark pine cones by squirrels tended to minimize differences in the densities of whitebark pine cones in middens, relative to stand whitebark pine basal area. Absolute densities of cones excavated by bears in Yellowstone varied relatively little among habitat types (between 2 and 4 cones/m^2), regardless of characteristic whitebark pine basal area (fig. 10). This was reflected in an asymptotic increase in the ratio of excavated cone density to whitebark pine basal area as basal area decreased. At low densities of mature whitebark pine, fewer squirrels' territories contained cone-producing trees, and despite preferential caching of whitebark pine cones by squirrels, there were fewer middens with whitebark pine cones available to bears. This phenomenon was evident in the positive relationship between stand whitebark basal area (x, in m^2/ha) and the probability of a midden being excavated by a bear ($\hat{y}$) ($\hat{y}$ = (942.8 + 13.36 X^{-2})) (Mattson and Reinhart 1987).

FORAGING STRATEGIES

Bear pine seed foraging, squirrel midden densities, and whitebark pine abundance are clearly related. A chronology of the trade-offs between midden density and whitebark pine basal area is evidenced by bear use of the 1987 pine seed crop in the Yellowstone area (table 6). During the earliest period of bear use in July, the number of cones excavated per cubic meter of excavation was higher than during August. These earliest feed sites occurred in a few favored, lower elevation habitats on south and southeast exposures, primarily in the ABLA/SPBE, ABLA/BERE, and ABLA/JUCO habitat types. These types were restricted to anomalous sites above 2,425 m elevation, and were more common at lower elevations. Whitebark pine cones probably matured earlier in these habitats, and because of high whitebark pine basal areas, the resident squirrels may have started caching whitebark pine cones earlier than in other stands with relatively less whitebark pine. Use through the first half of August was oriented toward stands with higher whitebark pine basal area and lower squirrel densities. The density of excavated material and cones was comparatively low during this period, as would be expected with the low rate of caching during early phases of whitebark pine cone harvest by squirrels (Hutchins and Lanner 1982). Peak use of pine seeds occurred between the middle of August and the middle of September, when bears used stands with higher squirrel densities. Bears excavated a higher density of cones during the last half of August, compared with the previous month, despite the lowest average number of excavated cones per cubic meter of excavation. By this time squirrel caching was at a uniformly high level (Hutchins and Lanner 1982), and squirrel midden density was probably most limiting to bear use of pine seeds. Although densities of excavations and excavated cones remained high during the last half of September, use generally declined. By this time marginal habitats had probably been fully exploited, and bears turned to using other foods or pine seed sites with relatively more whitebark pine and fewer squirrels. Full exploitation of the modest 1987 pine seed crop (Blanchard, this proceedings) by bears probably occurred by the end of September; subsequent October bear use of pine seeds dropped to very low levels.

We examined the relationship of various measures of cone-use density in habitats selected by bears to relative fecal volumes of pine seeds for different 1987 time periods (fig. 11). Although we had few data points, the derived relationships suggest constraints on bear use of pine seeds that were related to minimum densities of available whitebark cones in favored habitats. Such relationships further suggest that bears did not forage on pine seeds during 1987 when densities were less than approximately 39 available cones/midden and 56 available cones/km. The relationship of mean cones excavated per investigated telemetry location (relative pine seed use as documented by feed-site investigation) to relative pine seed scat volume, suggests that at <9 excavated cones/investigated relocation, pine seed use was likely to go undetected by scat analysis, at least at the 1987 sampling intensity (n = 472).

Table 6—Whitebark pine basal area, estimated squirrel densities, and parameters of bear use for whitebark pine feed sites for seasonal time periods, 1987. Squirrel midden densities were estimated by a site favorability index (Reinhart and Mattson, this proceedings), and use of any given midden was predicted from stand whitebark pine basal area (Mattson and Reinhart 1987)

Time period	n	(A) Estimated squirrel density (n/km)	(B) Whitebark pine basal area m²/ha $\bar{X}$	(B) s_x	Estimated density of midden use (n/km)	(D) Excavated material (m³/midden) $\bar{X}$	(D) s_x	(C x D) Estimated density of excavated material (m³/km)	(E) Minimum No. of excavated cones (n/midden) $\bar{X}$	(E) s_x	(C x E) Est. minimum density of excavated cones (n/km)	(E/D) Mean number of excavated cones per m³ of excavation
07/15-07/31	7	2.04	22.3	17.5	1.66	1.8	0.9	2.99	37.3	7.5	61.9	20.7
08/01-08/15	14	2.04	16.1	16.1	1.44	5.0	5.1	7.20	75.5	76.4	108.7	15.1
08/16-08/31	19	2.80	11.4	15.7	1.73	6.5	8.7	11.24	81.2	91.0	140.5	12.5
09/01-09/15	24	2.42	9.1	9.9	1.38	4.8	4.2	6.62	116.6	103.7	161.0	24.3
09/16-09/30	2	1.98	9.2	—	1.13	2.6	—	2.94	50.5	—	57.1	19.4

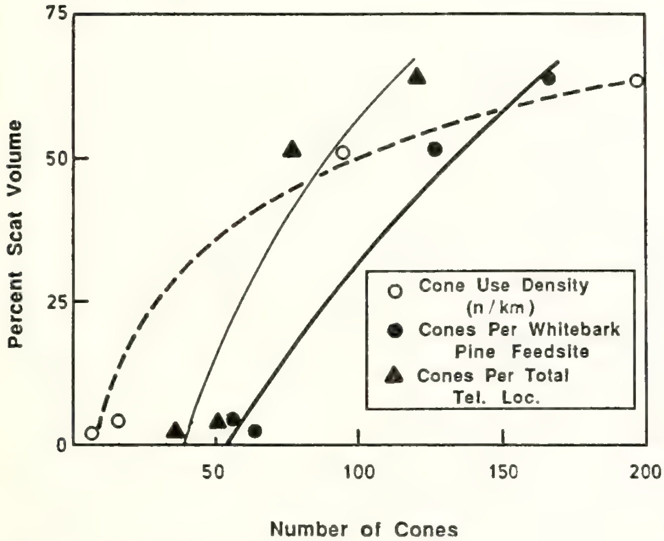

Figure 11—Relationships between percent scat volume, by month for 1987, and estimated excavated cone densities; per km, per whitebark pine seed feed site, and per telemetry location visited.

SUMMARY AND MANAGEMENT RECOMMENDATIONS

Stone pine seeds are a high-quality bear food because of their high triacerglycerol and energy content, relatively large size, and intermittent abundance. Wherever stone pines are relatively abundant, bears use them. Indehiscent stone pine cones are collected by arboreal rodents, principally red squirrels and Siberian chipmunks, into middens or caches. Preferential caching by these rodents, to a certain extent, minimizes the variation in stone pine seed production among sites and years. These rodents, therefore, are a key to the bear's ability to use pine seeds in most areas and to management of bear habitat for pine seed use.

Bears, midden locations and densities, the seasonal activities of squirrels, and whitebark pine abundance affect the seasonal foraging strategies of bears. Yellowstone bears were found to forage seeds primarily within the constraints of whitebark pine availability and squirrel midden densities. Bears made substantial use of stands with relatively low numbers of mature cone-producing whitebark pine, and were limited primarily by the absence of these trees altogether over substantial areas (more than approximately 1/2 ha). The greatest use of pine seeds typically occurred in LP cover types of the ABLA/VASC-PIAL phase because both squirrels and whitebark pine were relatively abundant in this type. At elevations >2,425 m, use of the ABLA/VAGL-VASC and ABLA/VASC-VASC h.t. phases was limited primarily by the lack of cone-producing whitebark pine, while use of the PIAL series was limited by lack of squirrels.

Management of bear habitat in drier portions of the Rocky Mountains for pine seed feeding depends on integrating squirrel and whitebark pine densities with bear foraging strategies. Stands of pure whitebark pine are of little use to most bears for pine seed foraging. However, these less fire-prone stands of pure whitebark pine may serve as important reservoirs of seed for dispersal by Clark's nutcrackers (*Nucifraga columbiana*) into burned areas.

Timber harvest has the potential to substantially impact bears through effects on squirrels and whitebark pine in habitats characterized by appreciable squirrel densities and mixed conifer species overstories that include whitebark pine. In many areas, stands and habitats important to bears for pine seed foraging occur at lower elevations of the whitebark pine zone and may contain few enough whitebark pine that their significance to bears is not recognized. Although whitebark pine is seral in much of the habitat used by bears to feed on pine seeds (Arno and Hoff 1989; Mattson and Reinhart, this proceedings), it may persist in stands for several hundred years as an appreciable cone producer. In addition, significant seed production is not likely to occur until trees are approximately 100 years old. Assuming 250 to 300 years to senescence of whitebark pine, 3 to 4 percent harvest of a landscape per decade would be sufficient to maintain productive whitebark pine stands. A few large-scale natural fires would serve the same purpose. Selective thinning of stands, even in favor of whitebark pine, would not

necessarily benefit bears because a reduction in stand basal area under most circumstances predictably results in a reduction of red squirrel density (Reinhart and Mattson, this proceedings). Because squirrels require mixed-species conifer stands to achieve even moderate densities (Reinhart and Mattson, this proceedings), cutting and replanting stands to pure or near-pure whitebark pine has little promise of enhancing bear habitat, even in 100 years. In conclusion, there seems little that active timber management can do to augment bear use of whitebark pine in drier portions of the Rocky Mountains, although in areas where timber harvest has already occurred or is planned for other reasons, judicious planting of whitebark pine in mixtures with other tree species will very likely benefit bears in the future.

In northwestern Montana, whitebark pine has been seriously depleted by (1) extensive infections of white pine blister rust (*Cronartium ribicola*), (2) the massive mountain pine beetle (*Dendroctonus ponderosae*) outbreaks of the 1970's and 1980's, and (3) by extensive logging of old-growth whitebark stands, especially in the Whitefish Range. Extensive use of whitebark pine cones and seeds in this area by both black and grizzly bears, as during the 1950's and 1960's (Jonkel 1967; Kendall and Arno, this proceedings; Tisch 1961), does not occur any more.

Cutting practices that favor whitebark pine are urgently needed in northwestern Montana. The mechanics of whitebark pine regeneration are poorly understood; extensive periods (100 or 1,000 years) may be required before optimal conditions for reseeding and survival may occur. The elimination of old-growth stands, even though the trees are slowly dying from blister rust, may doom whitebark pine in its northern range and cause the permanent loss of an important bear food.

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APPENDIX A. HABITAT TYPE NOMENCLATURE AND ACRONYMS (STEELE AND OTHERS 1983)

Acronym	Common name	Scientific name
PIAL series	Whitebark pine series	*Pinus albicaulis* series
ABLA/VASC-PIAL phase	Subalpine fir/Grouse whortleberry-Whitebark pine phase	*Abies lasiocarpa/ Vaccinium scoparium- P. albicaulis* phase
ABLA/VASC-VASC phase	Subalpine fir/Grouse whortleberry-Grouse whortleberry phase	*A. lasiocarpa / V. scoparium-V. scoparium* phase
ABLA/VAGL-VASC phase	Subalpine fir/Globe huckleberry-Grouse whortleberry phase	*A. lasiocarpa / V. globulare-V. scoparium* phase
ABLA/THOC h.t.	Subalpine fir/Western meadowrue h.t.	*A. lasiocarpa / Thalictrum occidentale* h.t.
ABLA/SPBE h.t.	Subalpine fir/Shiny-leaf spiraea h.t.	*A. lasiocarpa/Spiraea betulifolia* h.t.
ABLA/BERE h.t.	Subalpine fir/Oregon-grape h.t.	*A. lasiocarpa/Berberis repens* h.t.
ABLA/JUCO h.t.	Subalpine fir/Common juniper h.t.	*A. lasiocarpa/Juniperus communis* h.t.
ABLA/RIMO h.t.	Subalpine fir/Mountain gooseberry h.t.	*A. lasiocarpa/Ribes montigenum* h.t.
ABLA/ARCO h.t.	Subalpine fir/Heart-leaf arnica h.t.	*A. lasiocarpa/Arnica cordifolia* h.t.
ABLA/CACA h.t.	Subalpine fir/ bluejoint h.t.	*A. lasiocarpa/ Calamagrostis canadensis* h.t.

ELK AND MULE DEER USE OF WHITEBARK PINE FORESTS IN SOUTHWEST MONTANA: AN ECOLOGICAL PERSPECTIVE

Terry N. Lonner
David F. Pac

ABSTRACT

Summer-fall elk (Cervus elaphus nelsoni) *habitat use and relationships to logging were studied southwest of Butte in the Long Tom Creek area from 1971 to 1981 and mule deer* (Odocoileus hemionus hemionus) *population dynamics and habitat use were studied in the Bridger Mountains near Bozeman from 1971 to 1987. During these two studies elk and mule deer relationships to whitebark pine* (Pinus albicaulis) *communities were measured. Elk use of whitebark pine forests during the summer was incidental to the preferred use of high-mountain meadows. During fall, elk use of pure stands of whitebark pine at high elevations was negligible. However, fall elk use of whitebark pine was high when whitebark pine was associated with subalpine fir* (Abies lasiocarpa) *at lower elevations and there were high densities of tree regeneration. For female mule deer during summer and fall, forest cover types dominated by whitebark pine accounted for 15 and 3 percent of total habitat use, respectively. This value for adult males was 4 percent during summer. Insufficient data prevented an evaluation of habitat use by adult males during fall.*

Elk and mule deer selection of individual plant communities is discussed with reference to their mobility and broad ecological amplitude. The authors recommend that natural resource managers responsible for mobile, large mammal populations in mountain environments evaluate management alternatives from the perspective of how land uses will affect the entire ecological unit and its seasonal range components, regardless of public/private land ownership patterns. Management decisions thus made will be more successful in directing effective management of big game populations than decisions based on the importance of individual plant communities.

INTRODUCTION

Whitebark pine (*Pinus albicaulis*) forests are one of many habitat components found on elk (*Cervus elaphus nelsoni*) and mule deer (*Odocoileus hemionus hemionus*) summer-fall range in southwest Montana. These forests occur at the upper limit of the animals' summer-fall distribution. High-elevation zones occupied by whitebark forests provide a shorter period of occupancy for mule deer and elk than other habitats at lower elevations, due to weather conditions and site fertility. Most whitebark pine stands grow on weakly developed soils where nitrogen-fixing and other microbiotic activities are apparently restricted by low soil temperatures and high acidity (Arno and Hoff 1989).

Whitebark pine is often a dominant seral species of the upper subalpine and timberline habitat types that have been classified under the *Abies lasiocarpa* series and has been recognized as valuable for wildlife habitat, watershed protection, outdoor recreation, and esthetics (Arno and Hoff 1989; Pfister and others 1977). Forage production for livestock grazing and timber productivity are generally low where whitebark pine stands are prevalent. Silvicultural practices are frequently hampered by problems in road construction, harvesting, regeneration, and site protection.

In this paper we will present some pertinent results from research conducted on elk during the Long Tom Creek Elk Project (Lonner 1977), a research effort that was part of the Montana Cooperative Elk-Logging Study conducted from 1970 to 1985. Mule deer populations were studied in the Bridger Mountains from 1971 to 1987 as part of the Montana Statewide Deer Ecology Project. Data presented in this paper represent a portion of the results of the total study reported in detail by Pac and others (in preparation).

THE STUDY AREAS

Long Tom Creek

The Long Tom Creek study area (177 km^2) was located 20 km south of Anaconda, with the northwest corner in Deer Lodge County and the remainder in Silverbow County, MT (fig. 1). It served as spring, summer, and fall range for elk. The entire area was in public ownership; the Forest Service, U.S. Department of Agriculture, and the Montana Department of Fish, Wildlife and Parks (MDFWP) were responsible for administration of land management. The Beaverhead and Deerlodge National Forests accounted for 78 percent (94 km^2) and 9 percent (11 km^2) of the area, respectively. The remaining 13 percent (16 km^2) was managed by the MDFWP as part of the Mount Haggin Wildlife Management Area.

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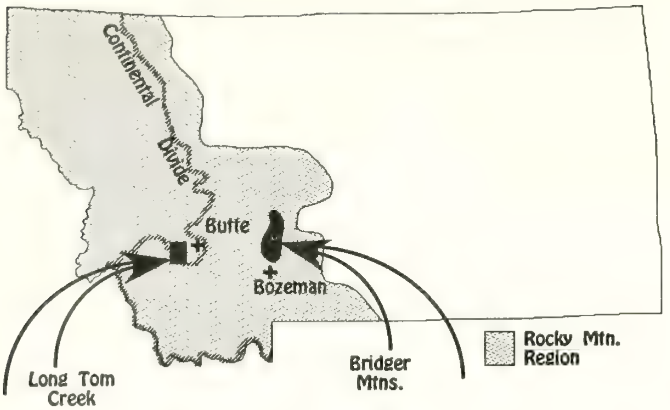

Figure 1—Location of the Long Tom Creek elk study area and Bridger Mountains mule deer study area in Montana.

Elevations ranged from 1,890 to 2,792 m, with moderate slope gradients except for a few areas that consisted of steep slopes and talus fields. The three prominent drainages on the study area (Johnson, Long Tom, and Jerry Creeks) were tributaries of the Big Hole River. Geologically, this area is probably a northward extension of the Pioneer Mountains. Numerous strongly scoured cirque basins as well as lateral, ground, and recessional moraines provide evidence of geologically recent glaciation in the valleys of both Long Tom Creek and Jerry Creek (Moore 1956). The Boulder Batholith formation occurs within the study area and sedimentary rocks of Proterozoic, Paleozoic, Mesozoic, and Cenozoic ages are also exposed in the area (Moore 1956).

The climate was generally mild during the summer and severe in winter, with the area usually under snow cover from November through May. The annual mean temperature ranged from 38.5 to 41.7 °F during 1972 to 1980, with wide fluctuations in daily and seasonal temperatures. Annual temperature extremes ranged from 88 and –19 °F in 1977 to 91 and –34 °F in 1979. Annual precipitation (1972 to 1980) ranged from 19 cm in 1974 to 49.7 cm in 1975. Fifty-five to 80 percent of the annual precipitation fell between April 1 and August 31 during the study (NOAA 1982). (Climatological data only approximate conditions on the study area because they were collected at the Divide weather station 15 km southeast of the study area at an elevation of 1,648 m.)

Vegetation in the area was dominated by lodgepole pine (*Pinus contorta*), Engelmann spruce (*Picea engelmannii*), subalpine fir (*Abies lasiocarpa*), and whitebark pine. There were 13 forest habitat types (Pfister and others 1977) identified in the study area, although only *Abies lasiocarpa-Pinus albicaulis/Vaccinium scoparium* (ABLA-PIAL/VASC h.t.), *Pinus albicaulis* h.t., (PIAL h.t.), and *Abies lasiocarpa/Vaccinium scoparium* (ABLA/VASC h.t.) were considered common. The ABLA/VASC h.t. was represented by the *Vaccinium scoparium* and *Thalictrum occidentale* phases. Three types were found occasionally: *Abies lasiocarpa/Calamagrostis canadensis* (ABLA/CACA h.t.), *Abies lasiocarpa/Luzula hitchcockii* (ABLA/LUHI h.t.)-VASC phase, and *Abies lasiocarpa/Calamagrostis rubescens* (ABLA/CARU h.t.). Five were found incidentally: *Pseudotsuga menziesii/Juniperus communis*, *Abies lasiocarpa/Vaccinium scoparium-Calamagrostis rubescens* phase, *Abies lasiocarpa/Xerophyllum tenax Vaccinium scoparium* phase, *Pseudotsuga menziesii/Calamagrostis rubescens*, and *Abies lasiocarpa/Linnaea borealis*.

Stands of limber pine (*Pinus flexilis*), Douglas-fir (*Pseudotsuga menziesii*), and alpine larch (*Larix lyallii*) also occurred in the area. Timber stands were aged as old as 325 years and ranged in stem density from scattered (200 trees/ha) to dense (7,900 trees/ha). Approximately 75 percent (90 km^2) of the study area was occupied by trees with a moderately dense (30 to 70 percent) to dense (>70 percent) canopy cover. This timber was interspersed with numerous xeric and mesic meadows and talus outcrops. Scattered timber sites (areas with canopy coverage less than 30 percent), natural meadows, and clearcuts amounted to 4.6, 12.6, and 6.6 percent of the study area, respectively. A few small lakes or ponds also existed.

Idaho fescue (*Festuca idahoensis*) and other dry-site graminoids and forbs commonly dominated natural dry parks. Various sedges (*Carex* spp.), wet-site graminoids, several forb species, and a few shrubs, including Labrador tea (*Ledum glandulosum*), characterized wet sedge meadows. The older logged sites had very little conifer regeneration, but a diversity of grasses and forbs grew in them. The newly logged sites (cut in 1975 to 1977), especially the clearcuts, had little revegetation by the end of the study.

Before the study, clearcut logging occurred in six units totalling 421 ha in the Jerry Creek drainage. Logging during the study (1975-77) involved 12 clearcuts and one selective cut altering 242 ha and removing 8.17 mbf of timber within the Long Tom Creek portion of the study area. These 12 clearcuts ranged in size from 6.4 to 49.2 ha with an average of 19.2 ha; the selective cut was 14.2 ha.

The Bridger Mountains

This mountain range is located just north of Bozeman, MT (fig. 1). It is one of a series of isolated frontal ranges located along the eastern flank of the Rocky Mountain cordillera. The total study area occupied nearly 2,000 km^2 that encompassed all habitats used by seven relatively distinct mule deer population/habitat units (Pac and others 1984). Average annual precipitation varied between 35 and 127 cm along an elevation gradient ranging from 1,365 to 2,947 m.

Soil parent materials consisted of consolidated sedimentary strata including a prominent calcareous substrate forming the backbone of the main Bridger Divide (McMannis 1955). Noncalcareous sandy or loam soils at lower elevations along the west slope arose from ancient arkoses (granitelike sandstones) and older metamorphic rocks. Andesitic sandstones at lower elevations along the east slope gave rise to similar soil types. Shale strata scattered throughout parts of the area resulted in clay soils.

Important plant communities associated with deer winter ranges included shrub/grasslands dominated by big sagebrush (*Artemisia tridentata*), antelope bitterbrush (*Purshia tridentata*), Rocky Mountain juniper (*Juniperus

scopulorum), Idaho fescue, and bluebunch wheatgrass (*Agropyron spicatum*). Narrow stringers of Douglas-fir often occur along stream courses within the winter range boundaries.

Habitats used by deer during spring, summer, and fall are characterized by an extensive coniferous forest at middle elevations comprised of numerous habitat types in the *Pseudotsuga menziesii*, *Pinus flexilis*, *Abies lasiocarpa*, and *Pinus albicaulis* habitat series described by Pfister and others (1977). Subalpine plant communities consist of clumps of stunted conifer interspersed with grass/forb meadows. Important species included Idaho fescue, slender wheatgrass (*Agropyron caninum*), sticky geranium (*Geranium viscosissimum*), and tall larkspur (*Delphinium occidentale*). The alpine meadow community occurred in scattered patches on high-elevation ridgetops. Species composition was relatively diverse and included *Carex* spp., Indian milkvetch (*Astragalus aboriginum*), spring parsley (*Cymopterus bipinnatus*), and eight-petal dryas (*Dryas octopetala*). Environmental characteristics along the east and west slope of the Bridger Mountains were described by Bucsis (1974), Nyberg (1980), Pac (1976), Rosgaard (1981), Steerey (1979), and Wilkins (1957).

Approximately 90 percent of the 360 km^2 of mule deer winter range was privately owned. Much of the spring, summer, and fall ranges along both sides of the Bridger Divide is administered by the Forest Service (Gallatin National Forest). A checkerboard pattern of public and private ownership occurs in the timbered foothills along the east slope.

Our discussion of mule deer use of whitebark pine communities in the Bridger Mountains pertains to only one of seven population/habitat units that occurred in the total study area. We referred to that ecological unit as the Northwest Slope. Over a period of 16 years it contained all seasonal ranges used by a population that averaged 650 adult deer in late winter. This was the only unit that contained significant stands of whitebark pine, which covered 13.6 km^2 (7 percent) of the total 186-km^2 area included within the Northwest Slope. All whitebark stands were classified as belonging to either the PIAL h.t. or the ABLA-PIAL/VASC h.t. (Pfister and others 1977). To improve interpretation of habitat selection by deer, we also described plant communities according to vegetation cover types.

METHODS

Long Tom Creek Study

Elk distribution and habitat use were determined primarily from elk "sign" recorded while periodically and systematically walking 11 circuitous foot routes. Routes were charted on aerial photographs and marked on the ground with colored plastic flagging material tied onto trees. Length ranged from 4.8 to 14.5 km; the average was 9 km. The routes were divided into segments, each sampling a homogeneous cover type. Segments longer than 0.5 km were usually divided to provide better sensitivity in measuring elk spatial distribution over the study area. A total of 700 segments were delineated; they ranged in length from 10 to 860 m, and averaged 158 m ± SE 4.7.

Each segment of the route system was assigned at least a general cover type (park, open-scattered forest, clearcut forest, medium-dense forest). Each segment with medium-dense forest was assigned a forest habitat type based on the Pfister and others (1977) classification system. Habitat types, however, often did not express the cover value of the forested segments. For each forested segment, tree densities were measured by species, diameter at breast height (d.b.h.), and height class. A cover type value from 1 to 5 was then assigned to each of these segments based on the amount of tree regeneration (all trees with a d.b.h. of less than 4 inches; seedlings were not counted). The five density classes of regeneration were: 1 (100 to 250), 2 (251 to 500), 3 (501 to 1,000), 4 (1,001 to 1,500), and 5 (1,500+ trees/acre). These five density classes of tree regeneration provided an index of hiding cover quality. This assumption was based on a signifi-cant relationship previously determined between sight distance (that distance at which approximately 90 percent of an elk is hidden) and regeneration density (Lonner 1977).

Routes were walked at least four times during summer and fall each year from 1972 through 1980. In 1973, 1974, and 1976 the routes were walked six, seven, and five times, respectively. It took about 1 week for two people to walk the entire route system. For analysis, data were organized so the replications completed each year represented three time periods: summer (June to mid-August), early fall or the rut (mid-August to late September) and fall (late September to late November). Only data from 1972 to 1976 were used for habitat analysis in this presentation.

Elk use during summer and early fall was the total number of fecal pellet groups counted since the last replication of the route system. Duplication of recording the same elk sign from one replication to another was avoided as much as possible. Elk sign during fall (October and November) could not be recorded directly due to snow cover. Therefore, during the first replication of the route system in June, elk use from the previous fall was determined by counting pellet groups with a form and consistency characteristic of the fall season.

All indexes of elk use for each segment were standardized by dividing the segment length into the total of fecal droppings; for example, if two fecal droppings were recorded for a particular segment that was 182 m long, the index of elk use was transformed into a ratio of 2/182 or 0.011.

Use of specific vegetation types was interpreted by statistically comparing the average use that occurred in each type during a particular season with the mean elk use of the route system for that season. Positive associations, or means significantly higher than the overall mean, indicate a preference or a concentration of elk use. Negative associations, or means significantly lower than the overall mean, may indicate an aversion or low concentration of elk use. Types listed as nonsignificant were those where elk use did not significantly deviate from the overall mean elk use.

However, elk use lower than the mean did not necessarily indicate an indifference or aversion to a particular habitat or cover type. Failure to select a particular habitat or cover type may only indicate that it may be available in excess of the needs of the elk during the time of the study.

Biotelemetry was also used to track radio-collared elk during the study, but these data were not used specifically for evaluating elk habitat relationships.

Bridger Mountain Study

A total of 46 individual cover types were defined according to dominant plant species as well as the structural characteristics of the overstory and understory layers. The distribution of individual cover types was mapped within the Northwest Slope population/habitat unit using 1:24,000 scale ortho-photo quads. This overlay map was digitized using the computer program GEOSCAN, a Houston Instruments Complot digitizing tablet, and Vax 11/780 computer.

Deer use of vegetation cover types during summer and fall was based on 1,466 aerial locations of 28 adult females and 13 adult males equipped with radio transmitters. All deer were relocated every 7 to 10 days. Sample size was not adequate to measure male use in fall.

In our analysis of deer habitat use, we employed computer-generated sampling plots or "scan circles." The conceptual basis for this method assumed that an animal location is not only related to the single vegetation cover type at that precise location; it may be significantly influenced by the mosaic of vegetation types within a prescribed area around the relocation point. We used a scan circle radius of 100 m to reflect the small seasonal home ranges of mule deer in this environment. We employed the GEOCALC computer software program written by Bill Hoskins for the Interagency Grizzly Bear Study, Bozeman, MT. This program used a dot grid method to calculate cover type areas within scan circles around deer and random relocation points.

For statistical analysis, individual cover types were combined into a hierarchical system. The primary stratum in the hierarchy described major vegetation zones along an elevation gradient. These consisted of steppe, montane forest, and subalpine/alpine. Secondary strata were categorized according to major structural differences in the overstory layer. The tertiary stratum in the hierarchy categorized forest cover types according to the dominant tree species in the overstory layer. Terminology generally follows standardized definitions (Hann and Jensen 1987).

Statistical comparisons of observed and expected use of cover types followed the technique described by Neu and others (1974) that employed a Bonferroni Z statistic.

RESULTS

Long Tom Creek Study

During the summer, elk use of the park cover type was significantly above the expected, while elk use of the medium-dense forest cover type was significantly below the expected (fig. 2A). Within this general type, ABLA/LUHI-VASC h.t. was the only forest type that received significant above-average elk use during the summer (fig. 2B). The whitebark pine habitat type received the least attention, but use was not significantly below the expected. Use of cover types within the two whitebark pine habitat types showed no statistical significance above or below the expected (fig. 2C).

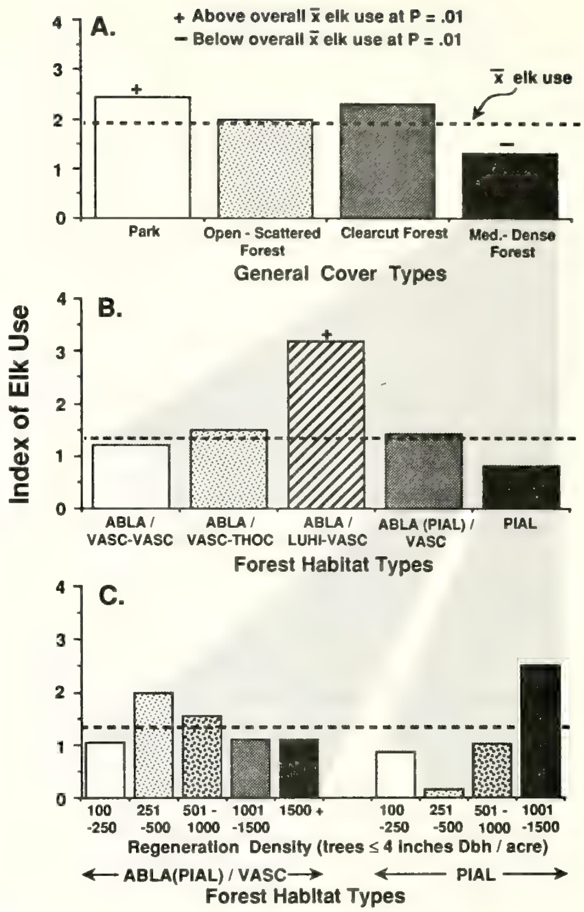

Figure 2—Summer elk use preference in the Long Tom Creek study area of: four general cover types (A), five forest habitat types (B), and regeneration densities with two forest habitat types with whitebark pine as a dominant tree species (C).

During the fall months, elk use of the open-scattered forest cover type decreased to a level significantly below the expected and elk use of the medium-dense forest cover type increased to a level that was similar to the expected (fig. 3A). Within this general cover type, elk use of four of the five forest habitat types was not different than expected. Elk use of the whitebark pine habitat type was significantly below the expected (fig. 3B). Elk use of cover types with the ABLA-PIAL/VASC and the PIAL habitat types was not different than expected except for a preference for cover type 5 within the ABLA-PIAL/VASC h.t. and a significant aversion to cover type 1 within the PIAL h.t. (fig. 3C).

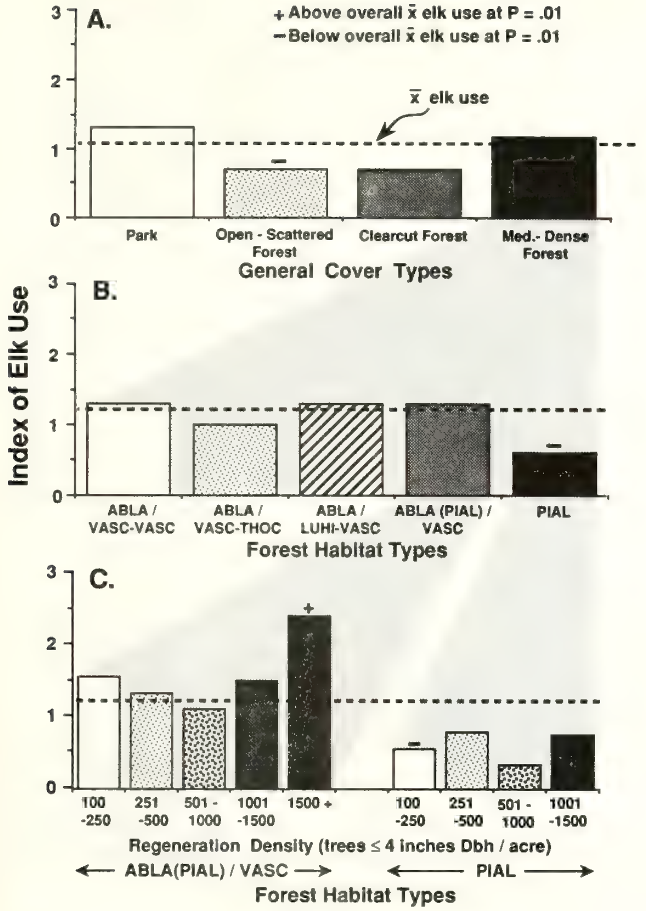

Figure 3—Fall elk use preference in the Long Tom Creek study area of: four general cover types (A), five forest habitat types (B), and regeneration densities within two forest habitat types with whitebark pine as a dominant tree species (C).

In summary, elk use of whitebark pine forests during the summer was incidental to the preferred use of high-mountain meadows. During fall, elk use of pure stands of whitebark pine at high elevations was negligible. However, elk use of whitebark pine was significant when whitebark pine was associated with subalpine fir at lower elevations and there were high densities of tree regeneration.

Bridger Mountain Study

During summer, more than 90 percent of all habitat use recorded for adult females occurred within the highly preferred montane forest zone (fig. 4A). Females avoided the steppe and subalpine/alpine zones. Much of their use was concentrated in two canopy classes of the mid-elevation forest, although only open-scattered canopy cover types were preferred (fig. 4B).

Although females preferred the two canopy classes of high-elevation forests during summer, total use was much less than mid-elevation forests (fig. 4B). Whitebark pine cover types in the high-elevation scattered and open forest were preferred and accounted for 7.3 percent of all use of vegetation types by adult females (fig. 4C). In the high-elevation medium-dense canopy forest, whitebark pine cover types were also preferred and accounted for 7.7 percent of all female use.

The montane forest continued to be very important to adult females during fall (fig. 5A). Adult female use of high-elevation forests declined sharply during the fall with a corresponding increase in use of mid-elevation forests with medium-dense canopies (fig. 5B). This change reflected snow accumulation at the high elevations. Combined use of all whitebark pine cover types did not exceed 3 percent during fall (fig. 5C) compared with a total of 15 percent in summer.

In summer, adult males preferred the montane forest, which accounted for 67 percent of all habitat use (fig. 6A). Males avoided the steppe and used the subalpine/alpine zone in proportion to its occurrence. Total male use of these two zones was substantially greater than that recorded for adult females. Males preferred the mid-elevation open-scattered canopy forests (fig. 6B), although

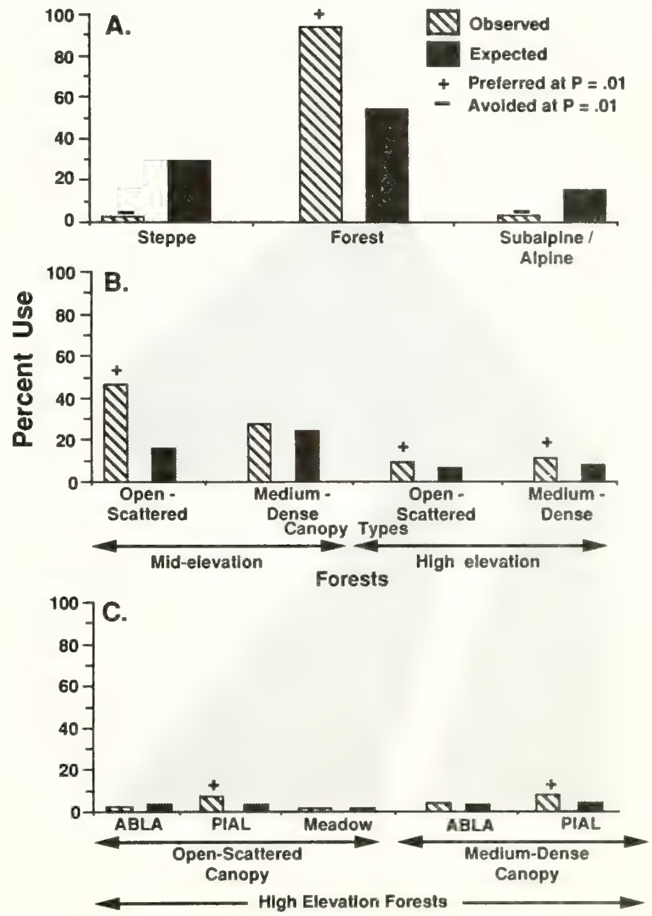

Figure 4—Adult female mule deer use during summer of: major vegetation zones (A), four categories of forest (B), and cover types categorized by dominant tree species in the high-elevation forest (C).

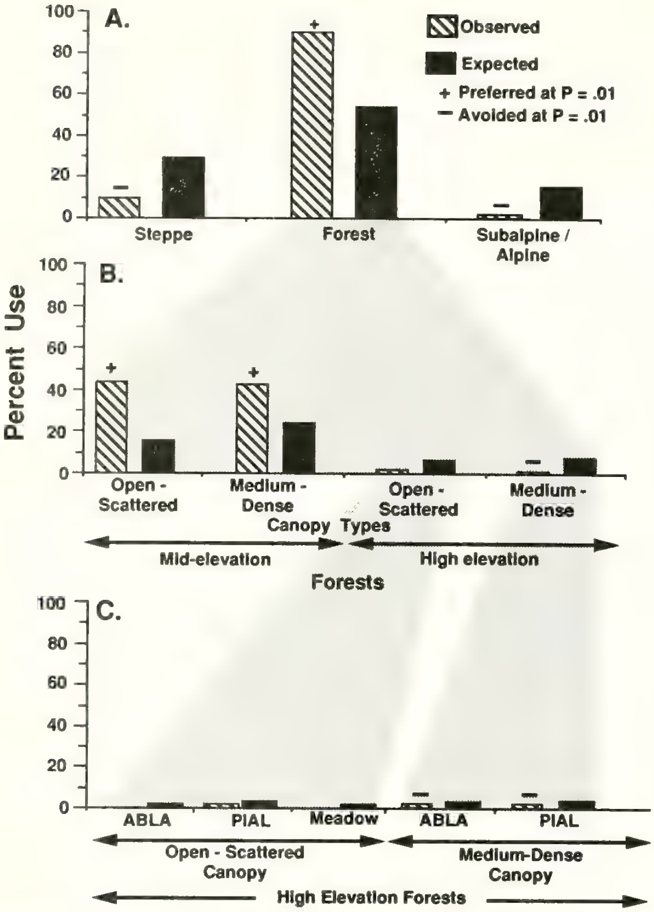

Figure 5—Adult female mule deer use during fall of: major vegetation zones (A), four categories of forest (B), and cover types categorized by dominant tree species in the high-elevation forest (C).

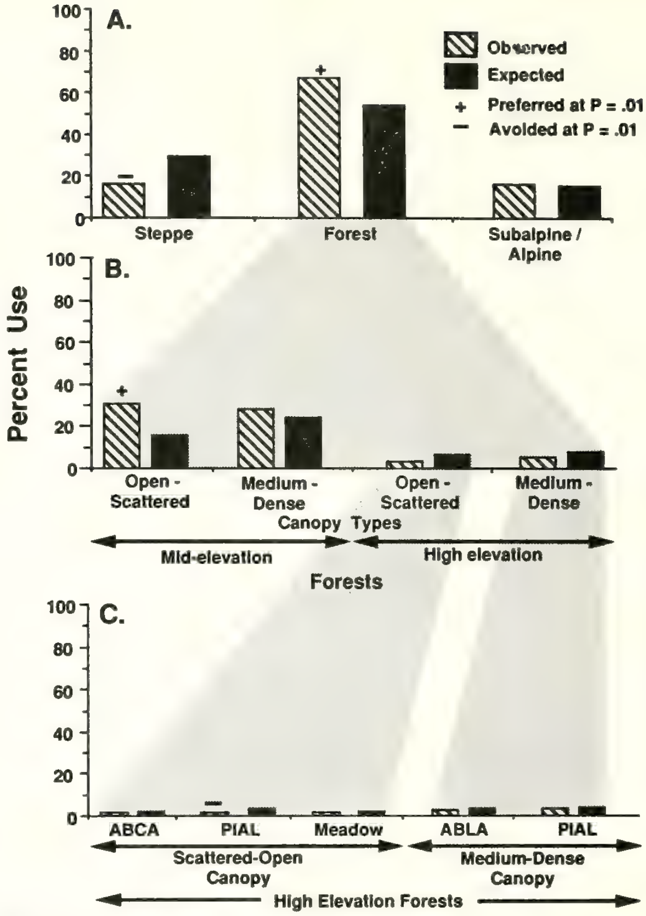

Figure 6—Adult male mule deer use during summer of: major vegetation zones (A), four categories of forest (B), and cover types categorized by dominant tree species in the high-elevation forest (C).

use by males was noticeably less than that recorded for females. Use of the mid-elevation medium-dense canopy forest was similar for each sex. Cover types dominated by Douglas-fir were most important to both sexes in the mid-elevation forests.

Male use of high-elevation forests in summer was not different than expected (fig. 6B). In the scattered-open canopy forest, whitebark pine cover types accounted for only 1 percent of total use (fig. 6C). Whitebark pine cover types in the medium-dense canopy forest accounted for 3 percent of use.

In summary, Douglas-fir cover types accounted for significantly more use than any other dominant tree species for both sexes. During summer, forest cover types dominated by Douglas-fir, whitebark pine, lodgepole pine, subalpine fir, and Engelmann spruce accounted for 58, 15, 12, 5, and 3 percent of total habitat use for adult females. These values for adult males were 48, 4, 9, 4, and 2 percent, respectively. During fall for adult females, this same ordering of use of forest cover types was 72, 3, 15, 0.5, and 0 percent. Insufficient data prevented an evaluation of habitat use by adult males during fall.

DISCUSSION

Animal selection of most vegetation communities appears related more to overstory and understory structure than to habitat types or individual species of plants (Lonner 1976). The broad ecological amplitude of animal species such as mule deer and elk causes difficulty in understanding and quantifying requirements for specific vegetation types such as whitebark pine communities or habitat types. Mobile animal species range freely over many vegetation types. It is implicit that difficulty will occur when a continuum of animal use is compared to a discrete classification system of vegetation, but it is important that big game habitat management plans and objectives recognize and address this dilemma.

A solution to this problem may be to express these relationships at a level of resolution above that of individual plant communities or habitat types. When evaluating elk or mule deer habitat relationships, the complete ecological unit or population/habitat unit that supports a migratory elk or mule deer population is the most critical entity to understand and quantify. An example of this is shown in figure 7 for the Northwest Slope mule deer population/

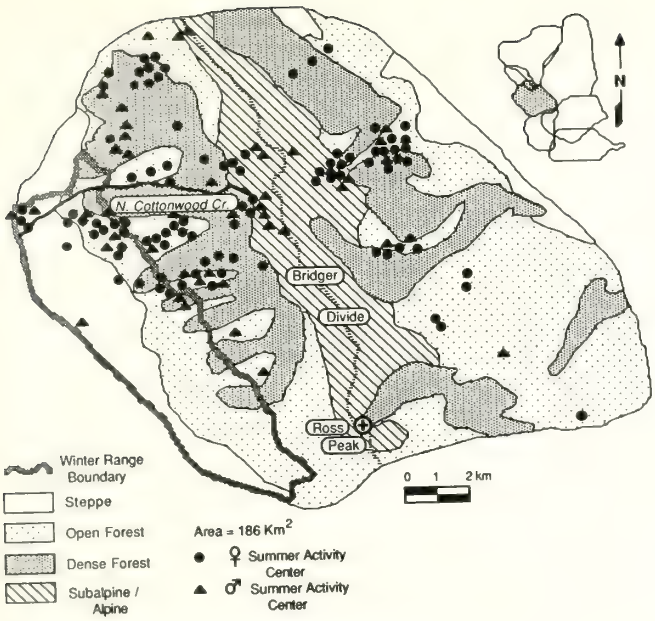

Figure 7—The Northwest Slope mule deer population/habitat unit in the Bridger Mountains.

habitat unit in the Bridger Mountains. This unit was based on the perimeter enclosing all relocations of individually marked deer associated with a particular winter range. Relocations of individual deer were summarized as activity centers.

This unit includes all seasonal ranges required to sustain the population. Each seasonal range, in turn, is usually comprised of a mosaic of individual plant communities. These lower order components have less individual importance to the welfare of an elk or deer population. At this level of habitat organization, mobile big game species can adjust to habitat changes much more easily than those that occur more broadly within the higher orders of organization.

We recommend that natural resource managers responsible for mobile, large mammal populations in mountain environments evaluate management alternatives from the perspective of how land uses will affect the entire ecological unit and its seasonal range components, regardless of public/private land ownership patterns. Management decisions made at this level of resolution will more successfully direct effective management of big game populations than decisions based on the importance of individual plant communities.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from Tad Weaver)—How much overlap occurs between adjacent mule deer population/habitat units in the Bridger Mountains?

A.—A total of 2,000 km^2 occurs within the seven mule deer population/habitat units in the Bridger Mountains and only 9 percent of this total area occurs within overlap zones.

Q. (from Tad Weaver)—If deer population/habitat units were obliterated across Montana and deer were allowed to recolonize the area, would the population/habitat units occur in the same places?

A.—Yes. The portion of a population/habitat unit that anchors it at a specific site is the location of suitable winter habitat. Summer range consists of mesic habitats in the general proximity of the winter range.

The location and distribution of winter ranges are very site specific and relate to special conditions of climate and topography. As long as these factors remain similar, then the location of population/habitat units will remain generally constant.

WHITEBARK PINE SEED DISPERSAL AND ESTABLISHMENT: WHO'S RESPONSIBLE?

Harry E. Hutchins

ABSTRACT

Whitebark pine (Pinus albicaulis) *has many characteristics that typify an animal-dispersed plant species. This paper outlines the role of individual animal species involved in the dispersal and establishment of whitebark pine seeds in Wyoming. Red squirrels harvested 63.7 percent of the seed, and Clark's nutcracker 36.1 percent in large forested tracts. Seeds from open-grown trees are almost entirely harvested by nutcrackers (99.4 percent) with less than 1 percent going to ground squirrels, chipmunks, Steller's jay, ravens, and other birds. The behaviors of animals that foraged on the pine seed and their influence on whitebark pine are discussed. Only Clark's nutcracker dispersed the seed in a way that might lead to the establishment of whitebark pine seedlings. Nutcracker caches on the open meadow ridges faced less predation than forest seed caches, so it appears to be more profitable for both the tree and the nutcracker to have seeds cached in the meadow.*

INTRODUCTION

Until recently whitebark pine (*Pinus albicaulis*) was thought to disperse its seeds by the cone falling to the ground and decaying. New trees would then establish in the rotting residue of the indehiscent cones (Day 1967), or the cone would simply disintegrate (Shaw 1914; Weaver and Dale 1974). But what of those lone sentinels on the sides of rocky cliffs and scattered individuals along subalpine moraines? Or the seedlings establishing under a lodgepole pine (*P. contorta*) forest canopy several miles from a mature whitebark pine tree?

When I first undertook this study the evidence began to mount implicating birds and mammals in the dispersal and subsequent establishment of whitebark pine (Tomback 1978; Vander Wall and Balda 1977). In this paper I will outline my findings concerning the animal species that were observed foraging on, and dispersing, whitebark pine seeds. These data will be supplemented by other authors who can add to this discussion. My observations were primarily made from July 1979 to September 1981 in the Rocky Mountains of Wyoming. Additional observations have been made on whitebark and other wingless-seeded pines from 1982 to 1987.

Paper presented at the Symposium on Whitebark Pine Ecosystems: Ecology and Management of a High-Mountain Resource, Bozeman, MT, March 29-31, 1989.

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STUDY SITES

The study was primarily conducted at Squaw Basin, Bridger-Teton National Forest, WY. This area of high-elevation meadows offered distant views of bird activity, whitebark pine growing in both contiguous forest and open-grown situations, and an abundant cone crop for whitebark pine during 1980. Besides whitebark pine, the forest stands were composed of Engelmann spruce (*Picea engelmannii*), subalpine fir (*Abies lasiocarpa*), and a minor amount of lodgepole pine. The moraine meadow ridges were pioneered by lone whitebark pine. This provided an opportunity to study two different types of communities—forest and meadow.

Observations of animal activity were also made at Surprise Lake (2,960 m, Grand Teton National Park, WY) and Mount Washburn (2,680 to 3,140 m, Yellowstone National Park, WY). These areas were similar to the Squaw Basin site except they lacked open-grown, cone-bearing trees. Details on the study sites can be found in Hutchins and Lanner (1982) and Vander Wall and Hutchins (1983).

METHODS

Several cone-bearing whitebark pines were chosen for observation in both continuous forest (red squirrels were present) and in open meadows at least several hundred meters from the nearest forest edge (these sites lacked squirrels). In each of these two types of sites, 1,005 whitebark pine cones were observed during the period from July 3 to November 2, 1980. The cones were scattered among several mature trees and were counted at 1- to 2-week intervals using a 15-25 by 60-mm spotting scope. Counts were made by standing in a specific marked location and mapping the cones on clear acetate. Changes in the cone map at each observation were recorded, including the partial removal of a cone. Cone count data were converted into seeds using an empirically derived value for the mean number of seeds per cone (50.4 seeds/cone) (Hutchins 1982). Partially consumed cones were tallied by estimating from the ground the percentage of seed remaining as described in Hutchins and Lanner (1982). The seed harvest data were then plotted against cumulative time for both forest and meadow sites (Hutchins and Lanner 1982).

At each observation date samples of seeds were collected to determine maturity and condition. The number of filled, discolored, insect-attacked, and second-year-aborted ovules were tallied. Mean dry weight of shelled seeds, seed coat thickness, and caloric content of shelled seeds were all obtained. Germination tests were also conducted with seeds collected at 10 collection dates during the 1980 field season.

Seedfall (caused by animal foraging) below the tree was estimated by placing five 1-m^2 wire mesh seed traps randomly below trees. The tops of the seed traps were designed to let seed fall through, but to exclude rodents. Data on the number of cones in the tree, the area of the tree crown, and the number of seeds falling per square meter were used to estimate the magnitude of seed fall.

Predation on seed caches of whitebark pine was also studied in 1979 and 1980. I simulated three types of caches: (1) seed that lands on the soil surface from foraging accidents, (2) seed cached at a depth of 3 cm simulating Clark's nutcracker (*Nucifraga columbiana*) activity, and (3) seed cached at 7-cm deep, which simulates the most shallow red squirrel seed cache. Each individual cache contained 10 seeds.

Animal/time/budget data were collected for the diurnal species found foraging in the whitebark pine ecosystem. Both quantitative and qualitative observations were made of the various activities and behaviors of the animals; these methods were detailed by Hutchins and Lanner (1982).

Red squirrel middens were also analyzed and compared with 25 random plots to determine tree establishment on these seed/cone caching areas. A split-plot Analysis of Variance and Least Significant Difference multiple mean test (p = 0.05 and 0.01) were performed on these data to identify significant differences. Tree seedlings were also studied to determine the year of establishment.

RESULTS

Seed Development

Hutchins and Lanner (1982) monitored seed development and found mean seed coat thickness and seed weight to be significantly greater during the August 31 to November 2 collecting period than before these dates. Clark's nutcrackers were unable to extract whole seed from a cone until August 13 due to the thin, fragile seed coats. The characteristic shell fragments of an unripened "nutcracker cone" were left as evidence of their foraging attempts (fig. 1). Thus, nutcrackers were unable to cache whole seed until after this date.

By September 7-10, the cones had dried and turned a dull brown from their previous moist, pitch-filled, purple color. Whitebark pine cones are often referred to as indehiscent, however, about 25 percent of the cones collected after September 7 parted their scales slightly (4 to 8 mm; n = 141). This still was not enough of an opening to allow the seeds to fall out of their own accord.

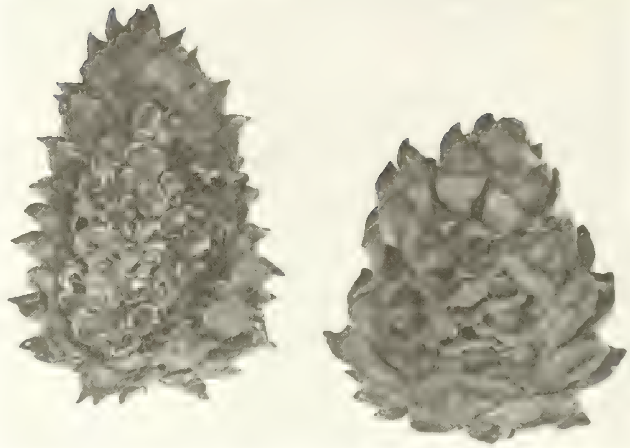

Figure 1—Typical Clark's nutcracker damage to whitebark pine cones. On the left, damage before the seed coat has developed; on the right, nutcracker damage from mid-September, after the cone had dried.

Seed Crop Depletion

Figure 2 (from Hutchins and Lanner 1982) shows that seed crop depletion followed a logistic curve (r^2 = 0.99 in the forest and r^2 = 0.96 in the meadow). Seed harvesting began somewhat earlier in the forest than in the meadow. In fact, about 50 percent of the seed crop had been harvested in the forest by August 31, while in the meadow this point was not attained until September 25. As seen on the graph, no seeds remained from this mast year in the forest stands by November 1. Only 0.1 percent of the seeds still resided in the tree crowns of the meadow trees, and these were no longer there when checked on June 27, 1981.

Even after several thousand hours in whitebark pine forests, I have never observed a whitebark pine cone falling from a tree without being aided by an animal. We have even bagged several cones in a double layer of hardware mesh to protect them from animals. Clark's nutcracker hammered right through the mesh to get at the seed after November when the cone crop was exhausted. Those that remained never abscised (Lanner 1982), as is sometimes mentioned in the literature. Analysis of seed traps below mature trees showed that 4.2 percent of the seed was dropped to the soil surface by foraging animals.

Seed Cache Predation

No seeds scattered in various locations on the soil surface of the forest or meadow survived to the following July in the simulated caching study (table 1). Seeds cached at nutcracker depth (3 cm) in the forest had a much greater predation rate than those cached in the meadow. Those seeds cached at the shallowest squirrel depth known (7 cm) had 100 percent survival of all artificial caches.

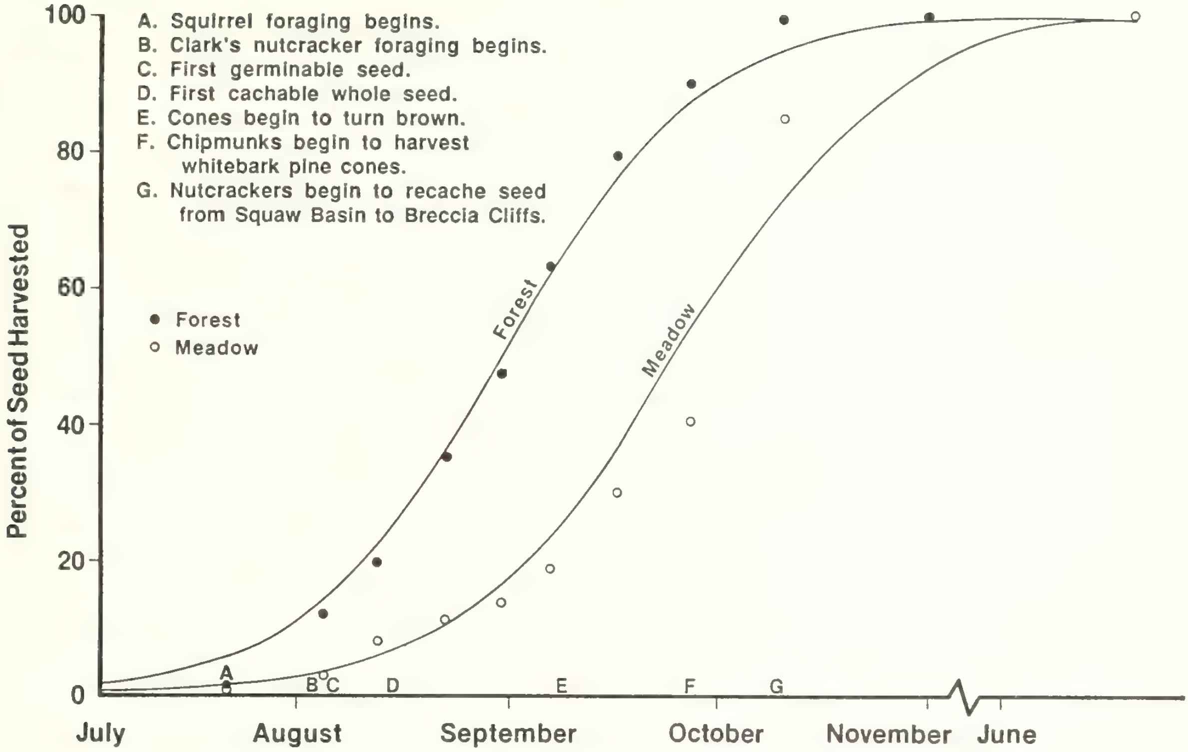

Figure 2—Seasonal course of whitebark pine seed harvest by vertebrates in Squaw Basin, WY, in 1980.

Animal Interactions With Whitebark Pine Seed

A variety of active diurnal animals were observed in or under whitebark pine trees. Many of these, however, were never observed foraging on whitebark pine seed. These nonforagers include: gray jay (*Perisoreus canadensis*), common flicker (*Colaptus auratus*), Cassin's finch (*Corapodacus cassinii*), rosy finch (*Leucosticte* spp.), pine siskin (*Spinus pinus*), dark-eyed junco (*Junco hymelis*), black-billed magpie (*Pica pica*), pine marten (*Martes americana*), coyote (*Canis latrans*), and weasel (*Mustela* spp.).

Table 1—Percent survival rates of simulated seed caches at three soil depths: surface, 3 cm (simulated nutcracker cache), and 7 cm (simulated squirrel)

	Surface	3 cm	7 cm
1979-80			
Forest (n = 3)[1]	0	43.3	100
Meadow (n = 3)	0	100.0	100
1980-81			
Forest (n = 12)	0	10.0	—
Meadow (n = 8)	0	62.9	—

[1]n = the number of cache replications, 10 seeds per cache.

Many feces of the mammal species listed above were examined, but no evidence of whitebark pine seeds was found. Gray jays were commonly found in the crowns of whitebark pine, but were only observed hawking insects and caching fresh carrion or boluses in pine branches. Dow (1965) found this species has little interest in pine seed during feeding trials, although Turcek and Kelso (1968) described its Eurasian cousin, the European jay (*P. infaustus*), as having been observed taking and caching Siberian stone pine (*Pinus sibirica*).

The other birds I have listed do not possess the anatomical adaptations or requisite behaviors to disperse seeds and thus promote establishment of whitebark pine—except possibly the magpie (Smith and Balda 1979). But in the thousands of hours I have spent observing animals in whitebark pine forests throughout its range, I have observed only two magpies, and both of these were flying swiftly over the trees toward lower elevations. Due to the rarity of this species in whitebark pine forests, any potential harvesting of seed would probably be unimportant.

Many species were found foraging on whitebark pine cones (table 2). At this point I would like to take a closer look at their role in the dispersal and establishment of this pine.

Clark's Nutcracker—Nutcrackers were the most common resident bird to visit the whitebark pine trees (Hutchins and Lanner 1982). They were scattered about whitebark pine stands in loose flocks foraging and caching seed of this tree. They are dependent on these caches year round (Giuntoli and Mewaldt 1978; Vander Wall and Balda 1977; Vander Wall and Hutchins 1983).

Nutcrackers were observed harvesting seed as early as July 13, 1979. During July, however, they appeared only to be testing the cones for ripeness and primarily feeding on the previous year's caches until mid-August. Seeds harvested at this time were lost to regeneration because the seed coats were broken and the seed was ungerminable until August 13. In 1980, the birds were able to successfully harvest whole, developed seed by August 15.

Table 2—Summary of animals known to forage on whitebark pine seed

Species	Date when foraging begins	Overlap with WBP range	Dependence on WBP in the subalpine
		Birds	
Clark's nutcracker	2nd week of July	all	high
Steller's jay	1st week of September	all	low
Common raven	1st week of September	all	low
White-headed woodpecker[1]	unknown	N. Cascades to Sierra Nevada	unknown
Hairy Woodpecker[1]	unknown	all	unknown
Williamson's sapsucker[1]	unknown	all	unknown
Mountain chickadee	1st week of September	all	low
Red-breasted nuthatch	1st week of September	all	low
White-breasted nuthatch[1]	unknown	all	unknown
Cassin's finch[1]	unknown	all	low
Red crossbill[1]	unknown	all	unknown
Pine grosbeak	1st week of September	all	low
		Mammals	
Red squirrel	2nd week of July	all except Cascades, Sierra Nevada	high
Chickaree[1]	unknown	CA, WA, OR	high (?)
Chipmunk	3rd week in September	all	low
Golden-mantled ground squirrel	3rd week in August	all	unknown
Black bear	anytime - raid middens	all except Nevada	high
Grizzly bear	anytime - raid middens	Rocky Mountains	high
New World mice, voles	unknown	all	unknown

[1]Foraging of these species has only been observed in the Sierra Nevadas.

Nutcrackers harvested seed from cones at increasingly faster rates (Hutchins and Lanner 1982) through early October, when seed became hard to find (fig. 2). Nutcrackers were never seen attempting to harvest Engelmann spruce or lodgepole pine even as the whitebark pine seed crop dwindled in October.

As the seed supply in the tree crowns was depleted, nutcrackers continued to search cones in the crown for stray seeds. I recorded one bird checking more than 50 cones for a period of 613 seconds without finding a single seed.

By November 2, it appeared nutcrackers were almost totally dependent upon their new seed caches, and would remain so until the following August. These caches were placed just below the soil surface (2 to 3 cm) and ranged in size from 1 to 14 seeds ($\bar{x} = 3.2 \pm 2.8$ seeds/cache) (fig. 3). These data agree closely with Tomback (1978) and Vander Wall and Balda (1977), but I found a much greater occurrence of single-seed caches than Tomback.

Caches were made in a variety of locations on the various study areas. Sometimes the birds marked their caches by placing small sticks or stones on them. More commonly the caches were left unmarked, at least as far as we humans are concerned. I observed caching in wet moss, at the base of trees, the base of annuals, the base of rocks, or not near any discernible landmark. The birds cached in the densely shaded forest or in open meadows; on northeast facing slopes where the snow may linger until August; or more commonly on the sunny, dry southwest-facing slopes. Tomback (1978) never observed caching in damp areas or on stream banks, and suggested that seed spoilage occurs on these wet sites. Hutchins and Lanner (1982), however, were able to successfully germinate seeds from a wet cone found buried in a squirrel midden.

Transport distances varied greatly. Seeds were placed as close as 50 m from the site of the harvested tree, or were transported at least 3.5 km to the Breccia Cliffs on the edge of the Squaw Basin site. With little seed left in the trees by mid-October, the birds began retrieving many of their caches made in the Squaw Basin meadows and recaching them on the southwest-facing slopes of the Breccia Cliffs.

Large flocks of nutcrackers would often cache seed together. At Mount Washburn a flock estimated at 150 birds was seen caching seed under an open-grown whitebark pine stand, with 10 to 15 birds within a 10-m² area. No aggression occurred among the birds during these observations.

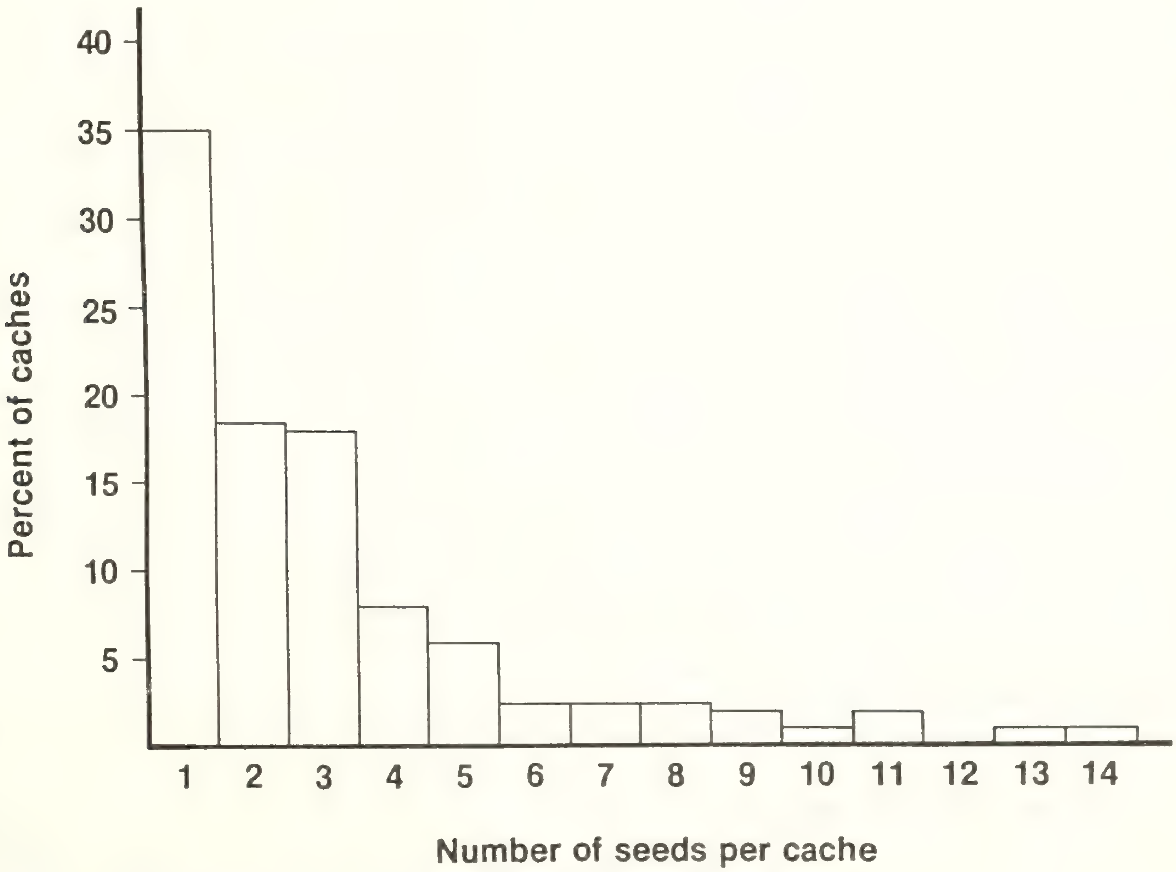

Figure 3—Clark's nutcracker cache size frequency. Data from 157 observations made at several locations in Wyoming.

By November 2, 1980, snow covered many of the caching areas for the winter. Nutcrackers were observed on several occasions successfully pecking through as much as 25 cm of snow and ice to retrieve a cache. The Togwotee Pass area may receive up to 1,500 cm of snow a year, yet the windswept ridges and south-facing slopes remain exposed enough for the birds to retrieve their caches. Caches on the northeast-facing slopes and under the forest canopy are more frequently used during June, July, and August, as the snow recedes from these sites last (Vander Wall and Hutchins 1983).

The number of seeds an individual nutcracker caches annually has been estimated in several studies. The numbers for whitebark pine range from 32,000 in the Sierras (Tomback 1982) to 98,000 in the Rocky Mountains (Hutchins and Lanner 1982). Because of the number of variables that must be considered (such as flight distances and the amount of available seed), these estimates vary a great deal from site to site and year to year.

Studies by Vander Wall and Balda (1977) and Tomback (1982) estimated that an individual bird caches several times more seed than it needs to survive through the winter and early spring. At that time other food items become available—although the nutcrackers continue to use their caches heavily until the new cone crop begins to mature. This leaves many unused caches for potential germination and establishment of whitebark pine seedlings (Hutchins and Lanner 1982).

Clark's nutcracker stands out from all the other potential seed dispersers in two major ways. First, it consistently disperses seed in a way that increases the chance of seedling establishment. The seed is placed just below the soil surface and hidden from seed predators (Hutchins and Lanner 1982; Lanner 1980).

Second, nutcrackers scatter caches across the landscape—both long and short distances from the source trees. Dispersal distances of up to 22 km have been observed by Vander Wall and Balda (1977). Also, the scattering of their caches again reduces predation.

Steller's Jay (*Cyanocitta stelleri*)—Unlike the Steller's jays of the southwestern and central Rocky Mountains, the birds of the Yellowstone ecosystem are shy and silent. Consequently, they are difficult to follow and observe. They are primarily solitary foragers and uncommon visitors to the whitebark pine forest. These birds did not forage for whitebark pine seed until early September when the cones dried and the scales separated slightly. Their bill structure does not approach the efficiency of the nutcracker's in prying apart cone scales to get to the seed (Vander Wall and Balda 1981), thus they were often only able to extract seed from cones that had been exposed by nutcrackers. These jays harvested seed from the ground (14 percent of their observed foraging time) as well as from the cones (24.5 percent). The seed was always placed between their feet and hammered with their bill to crack the hull, whereas nutcrackers primarily cracked the seed between their mandibles.

Observations showed Steller's jays either pouched their seed in their elastic esophagus for later caching, or consumed the seed by breaking it into small pieces. Thus, they could not possibly pass the seed through their digestive system and disperse it in that manner.

Although Steller's jays were observed caching whitebark pine seeds on seven occasions, none of these were in the soil. The birds placed the pine seeds in the crotch of a tree, a densely foliated witches-broom, or under dense lichen growth along a tree branch. The largest number of seeds I observed being pouched at one time by this species was five, although data from Vander Wall and Balda (1981) indicate these birds could hold up to 32 seeds per pouch load. Because this species does not cache whitebark pine seed in the soil, it is an improbable vector for seedling establishment.

As the snow melted, Steller's jays fed heavily on the sprouting spring beauties (*Claytonia lanceolata*), pulling the corm from the ground and consuming the plant just as it emerged. Some of these were possibly cached for later use.

Raven (*Corvus corax*)—A third corvid observed foraging on whitebark pine seed was the common raven. These birds had a great deal of difficulty extracting seed from whitebark pine cones with their thick, long bills. They dropped most of the seed when foraging (Hutchins and Lanner 1982). Caching of carrion was observed with this species, but no observations were made of seed caching. More observations of this species in whitebark pine communities need to be made to confirm my observations. Reimers (1959, cited in Turcek and Kelso 1968), described observations of ravens caching Japanese (*Pinus pumila*) and Siberian stone pine (*P. sibirica*), although it was not clear in what type of substrate.

Pine Grosbeak (*Pinicola enucleator*)—Pine grosbeaks primarily foraged on whitebark pine seed that had been exposed by Clark's nutcrackers breaking off cone scales. Their large conical beaks also enabled them to tear away cone scales to get at seed. Their foraging rates were very slow compared to the nutcrackers' due to their technique, and as a consequence, they had little influence on the depletion of the whitebark pine cone crop.

Grosbeaks are not known to cache food (Smith and Balda 1979; Vander Wall in press). During my observations, they cracked the seed coat and consumed the seed in the tree crown. It is unlikely that they could pass an intact seed through their digestive tracts.

Mountain Chickadee (*Parus gambeli*) and Red-Breasted Nuthatch (*Sitta canadensis*)—These two species occasionally searched through the whitebark pine cones during September after the seeds were exposed by nutcrackers. Both these species almost always dropped the seed from the tree crown because the seeds were too large for them to handle. Their unsuccessful foraging bouts contributed to seed found on the soil surface, which was later consumed by other animals. Neither bird species was observed caching whitebark pine seed, although they are known to cache seeds of smaller seeded conifer species under bark (Smith and Balda 1979).

Red Squirrel (*Tamiasciurus hudsonicus*)—Red squirrels are common residents of whitebark pine forests. In fact they were the second most commonly observed vertebrate next to the Clark's nutcracker (Hutchins and Lanner 1982). These mammals actively defend their territories (Smith 1968), and like nutcrackers, harvest whitebark pine cones and seeds as a fall and winter food source. Red squirrels were not observed in the meadows.

Red squirrels spent most of their foraging time (75.8 percent) on whitebark pine cones or recovering dropped whitebark pine seeds. Most of the rest of the observed foraging activities were collecting Engelmann spruce cones (11.3 percent) and harvesting seeds of herbaceous plants (12.9 percent).

Red squirrels began harvesting cones as early as nutcrackers harvested seeds (July 13, 1979), but did so more intensely during July while the nutcrackers relied more heavily on the previous year's caches (fig. 2). Their foraging rate is much higher than that of the other mammals discussed in this paper because they usually harvest an entire cone (50 or more seeds in one chunk).

Squirrels were observed pulling cones off the branches with their teeth 72 percent of the time (n = 71 observations), as opposed to cutting the subtending branch. Halvorson (1985) presented an interesting discussion on the effects of cone cutting by squirrels on tree growth and cone production. With whitebark pine, however, because squirrels seldom cut the branches, little change occurs in growth form or cone production.

Red squirrels often would leave cones on the ground below the tree where they were cut for up to 3 days before caching them in their middens. Seeds in cones were consumed until August 15 when squirrel activity turned more toward caching cones for a winter food supply. This date coincides with the onset of seed germinability of whitebark pine (fig. 2).

Cone caching began on August 4 at Squaw Basin. Caching of other conifer species began later with Engelmann spruce on August 18, 1980, subalpine fir on September 11, 1980, and lodgepole pine on September 27, 1980. All cones were stored on a midden (n = 114). These midden areas can be quite extensive and are composed of many years of cone debris above the soil surface (Finley 1969; Smith 1970). Of the time spent caching food, 61.4 percent was devoted to whitebark pine cones and 16.9 percent to whitebark pine seeds. Foraging on the cones of other conifers in the subalpine forest accounted for most of the rest of the caching time (7,304 seconds of observation). Some caching of mushrooms and herbaceous seed took place also.

A second stage of caching began about September 16, 1980. At this time, squirrels began to make large seed caches from whitebark pine cones by extracting seed from the cone, running several meters to place a seed in a deeply dug hole, and then returning to the cone to acquire another seed. This slow and inefficient process took 63.8 ± 36.5 sec/seed cached (n = 34). These seed caches were placed 6.5- to 40.0-cm deep (n = 6); four were observed between 11- and 11.5-cm deep. The number of seeds per cache ranged from 14-55 ($\bar{x}$ = 28.8 ± 19.2 seeds/cache; n = 4), although Kendall (1981) found up to 176 seeds in a single hole. I examined the seeds from two squirrel caches and found all the seeds sound.

Red squirrels actively chased Clark's nutcrackers from the trees above their territories and their middens. On two occasions, however, I watched nutcrackers steal whitebark pine seeds from squirrel middens.

Chipmunk (*Eutamias* spp.)—Chipmunks seldom visit whitebark pine tree crowns, but do occur on both open meadow and forested sites. Most of their time is spent on the ground, usually near cover plants like sagebrush (*Artemisia tridentata*). They preferred herbaceous plant parts (lupine seed and grasses) on my subalpine study sites until the third week of September when these plants died back and presumably lost much of their nutritive value. At that time, chipmunks clumsily foraged on the remaining whitebark cone crop (~10 percent in the forest, 40 percent in the meadow). They also foraged on the small amount of seed below the trees, which had been dropped by any of the species discussed earlier. Heller (1971) similarly found that in the Sierra Nevada this species devotes little time to foraging on whitebark pine.

I found no evidence of chipmunks caching whitebark pine seed. Broadbooks (1958) found the cache depth of western chipmunks (*Eutamias amoenus*) to average 28 cm. They use these types of caches as a winter and spring food source when they are periodically aroused during hibernation (Vander Wall in press). I examined chipmunk burrows to a depth of 20 cm without finding any evidence of them harvesting and caching whitebark pine seed.

Chipmunks are known to scatter-hoard smaller amounts of seed in shallower caches from 2 to 5 cm in depth (Vander Wall in press). There appears to be little information on the use of these caches, how long they last, and how commonly this type of caching occurs with the pines of the western United States.

Although this species is often assumed to play a significant role in afforestation of pines, no data support this conjecture for whitebark pine. In fact, the necessary information to support this idea is lacking for any of the pine species (Gordon 1943; MacClintock 1970; Shtil'mark 1963; Tevis 1953). Kawamichi (1980) reported scatter hoarding of oak acorns at more reasonable depths (3 cm) in Japan by the Siberian chipmunk (*Eutamias sibiricus*). This chipmunk is known to occur in Siberian stone pine forests (Shtil'mark 1963). Still, the limited amount of seed these animals harvest apparently precludes them from being significant to whitebark pine establishment in the Rocky Mountains.

Golden-Mantled Ground Squirrel—The golden-mantled ground squirrel also consumes a limited amount of whitebark pine seed. This species will rarely climb trees to feed on cones, but more commonly feeds on seeds that fall to the ground through foraging accidents.

Ground squirrels will make caches in the ground, but like those of chipmunks, these caches are about 20 cm deep (MacClintock 1970). This species also begins hibernation quite early in September and would not have time to acquire much seed for storage. As with the chipmunk, few studies have been performed to determine ground squirrel foraging and caching behavior.

A recent study in pinyon-juniper in Colorado provided no evidence for pinyon pine (*Pinus edulis*) seed (also large and wingless) being harvested by deer mice, chipmunks, pocket mice, or the golden-mantled ground squirrel (Haufler and Nagy 1984). In fact, all but the ground squirrel preferred arthropods.

Nocturnal Rodents—This group of animals, made up primarily of mice and voles (Cricetidae), must also be considered as potental dispersal agents of whitebark pine seed. They were not directly observed in this study, but possible evidence of their foraging on whitebark pine seed was discovered by the shelled seed left behind on my simulated cache experiments.

Surface seed caches simulating the seed found on the ground indicate it will not last long (table 1). Most of the seed in these caches was consumed within 2 weeks after placement under trees and the shelled seed was left behind. Almost all of the shells were left behind at the cache site, indicating little if any caching was done.

There are two primary places cricetid rodents may obtain whitebark pine seed: (a) from seed that falls to the ground and (b) a discovered nutcracker cache. A small amount of seed (~4 percent of the seed crop) was found to fall to the forest floor in the mast year of 1980. About 69 percent of this seed was determined not viable by examination of the contents inside the shell.

Nocturnal rodents may also find and recover nutcracker caches. Although the rodents may recache the seed, it was probably already placed in a suitable site for seedling establishment by Clark's nutcracker. Thus, even if these Cricetidae relocate the seed to another cache, their positive effect on the establishment of whitebark pine is questionable at best.

Abbott and Quink (1970), working with eastern white pine (*Pinus strobus*), showed most caches by these rodents were made less than 15 m from the seed source. Thus, the habit of whitebark pine trees pioneering open meadows and disturbed areas does not arise from cricetid caches. Their study also stated that of those caches not recovered by the time the seed germinated, the germinated seedlings were soon consumed by these animals. This information coupled with the small amount of seed available on the ground for these rodents, indicates they could rarely be responsible for seedling establishment. Future studies need to look at this group of potential dispersal agents more closely to further delineate their role in whitebark pine ecosystems.

Grizzly and Black Bears—Bears (*Ursus arctos* and *U. americana*) primarily obtain seed from squirrel middens (Kendall 1981, 1983), although black bears are known to also break branches to harvest the seed (Tisch 1961). I examined more than 10 fecal deposits packed solidly with whitebark pine shell fragments of grizzly bears and found a total of three seeds left intact. Many black bear scats were also examined, and only one seed remained undamaged. These scats were all found within 25 m of a squirrel midden. If these seeds germinated in the bear scats, they would produce an insignificant number of whitebark pine seedlings.

Percentage of Seed Harvested by Each Animal

Using raw data from this study and from long-term behavioral observations of nutcrackers by Steve Vander Wall (1981), I have estimated the percentage of the 1980 seed crop harvested by the animals in the Greater Yellowstone Ecosystem.

On forested sites, about 63 percent of the seed was harvested by red squirrels and 36 percent by Clark's nutcracker. The other 1 percent was harvested by all other animals combined (table 3).

The story is quite different on meadow sites that have too few trees for squirrels to exist. Here the nutcrackers harvested almost the entire crop of whitebark pine seed (99 percent).

I am uncertain to what extent these percentages might vary between years and different sites, but they do give an indication of what is occurring in Rocky Mountain whitebark pine communities in relation to seed crop harvest.

Table 3—Estimate of whitebark pine seed harvested by various animals in Wyoming

Species	Mean seeds extracted/ minute[1]	Minutes spent foraging/ day[2]	Foraging days/ season	Seeds harvested/ individual	Number of individuals visiting trees	Seeds harvested by all individuals	
						Forest	Meadow[3]
						Percent	
Clark's Nutcracker	7.9	180	91	129,402	448	36.3	99.4
Steller's Jay	.7	120	55	4,620	11	<.1	.1
Raven	.6	30	53	954	15	<.1	<.1
Noncorvids	.7	120	56	4,704	43	.1	.3
Red squirrel	43.4	240	84	874,944	116	63.5	—
Chipmunk	1.7	120	35	7,140	10	<.1	.1

[1]Seasonal average from observations made from August 15 to October 11, 1980.
[2]Estimate made from observed daily activity patterns.
[3]Meadow area lacks squirrels.

DISCUSSION

Even during years of heavy cone crops, animals harvest nearly all of the seed crop by early November in the Rocky Mountains (Hutchins and Lanner 1982; Vander Wall 1981). By this time, no cones remain on the trees and many of those bagged with hardware cloth have been broken into by squirrels and nutcrackers. Seeds do not have a chance to survive long enough on the ground and germinate as suggested by Day (1967) and others. The seeds and cones, which have been dropped to the ground, are eaten within 3 weeks by various foragers.

A species cannot depend on chance regeneration to survive. Obviously whitebark pine has been very successful in naturally regenerating itself over millions of years. Through seed trap studies, I estimated about 4 percent of the seed crop is dropped to the ground through foraging accidents and only 30.5 percent of that seed was viable. Most of the seeds we see on the ground have been discarded by nutcrackers and squirrels, or dropped accidentally by other seed-foraging animals. They usually discard seeds that are of little food value (Vander Wall and Balda 1977). Consequently, seeds falling from trees to the ground are few in number, and of poor quality. If whitebark pine relied upon this method of regenerating, the tree would be extinct today.

Surveys of middens versus random nonmidden plots show that the middens had a significantly lower number of stems in the regeneration size classes (table 4). This may be due to (1) near-constant digging and searching for cones and seed by squirrels in their food stores, (2) a deep litter layer from cone debris, which is a very poor seed germination bed, and (3) the ability of squirrels to more readily find their seed/cone stores within a limited storage area. Consequently, we can disregard red squirrels as agents of whitebark pine regeneration.

One tree species that was found to be more abundant on squirrel middens was subalpine fir—in fact, I found it easy to locate middens from a distance by a cluster of fir trees. The youngest fir tree found on 25 middens surveyed was 6 years old; the youngest whitebark pine was 30 years.

Squirrels harvest most of the whitebark pine seed in the forest and they are the major seed predator on forested sites. Red squirrels should not, however, be chastised for the destruction of the whitebark pine seed crop.

Table 4—Number of stems by diameter class (cm), comparing squirrel middens and random forest plots. Each surface was sampled by 25 10-m² plots

Tree species	Surface	<1 cm	1-9 cm
Whitebark	midden	7	13
pine	random	[1]72	[1]119
Engelmann	midden	3	9
spruce	random	[1]79	[2]16
Subalpine	midden	[2]67	14
fir	random	10	2

[1]Significance = 0.01 (LSD multiple mean test).
[2]Significance = 0.05 (LSD multiple mean test).

We must remember their importance in collecting seed for grizzly and black bear use. The effect bears have on squirrel populations due to their midden raiding habits is unknown.

Nutcrackers are one of the most important biotic influences developing and changing subalpine communities. This species alone probably accounts for nearly all whitebark pine regeneration, except for chance happenings. Whitebark pine becomes established wherever the nutcracker caches the seed. I have found germinating seeds and observed caching in a wide variety of microhabitats, although nutcrackers may prefer certain sites. Several studies (Lanner 1982; Lanner and Vander Wall 1980; Snethen 1980; Tomback 1978; Vander Wall and Balda 1977) indicate south-facing slopes seem to be preferred. Where establishment actually occurs is another matter. Seedling establishment appears to be much more common on moister sites in the Rocky Mountains (Arno 1986; Arno and Hoff 1989; Vander Wall and Hutchins 1983) than in the Sierra Nevada (Tomback 1982).

As far as the bird and the tree are concerned, it is more profitable to cache in the open meadow. Less predation occurs on nutcracker caches in the meadow, and the small ridges are usually free of snow due to wind action. Consequently, the higher cache survival rate benefits tree regeneration as well as the survival of the nutcracker. This more than any factor may be why we see whitebark growing where we do—pioneering the exposed ridges, roadside cuts, burned sites (Lanner and Vander Wall 1980; Tomback 1986), and meadow swales.

Determining cache sites, however, can be difficult because nutcrackers will recache seeds. It appears that they forage on cones to get the seed out of the trees and down into the ground away from other seed eaters. Then as the seed crop becomes depleted in October, they spend their time recaching the seed over a much more dispersed area. This reduces loss to seed cache predators unlike the red squirrel cache loss to bears.

When nutcrackers forget where they placed a cache (Vander Wall 1982), or die, or a rodent does not discover the seed cache—it has a chance to germinate. By placing the seed in an excellent germination bed just below the soil surface (2-3 cm) and also hiding the seed from easy discovery by seed predators, the bird creates a new forest stand.

These whitebark pine trees modify the once-open subalpine landscape so other more shade-tolerant species such as Engelmann spruce and subalpine fir can establish themselves in this community (Arno 1989; Franklin and Dyrness 1973; Snethen 1980). The seed produced by whitebark pine attracts a large number of seed eaters (table 2), which in turn attract predators. During the summer/fall of 1980 at Squaw Basin, I recorded 10 hawk species (including the endangered peregrine falcon) and one owl species feeding among a large prey base of primarily seed eaters. After whitebark pines die, they become important to snag- and fallen-tree-dependent species as they decompose slowly. As previously discussed, both bear species consume large amounts of whitebark pine seed before denning in autumn. Also, whitebark pine often provides the only substantial

Table 5—Seed caching characteristics of animals that may potentially cache whitebark pine seed

Species	Substrate	Depth
Clark's nutcracker	soil	2-3 cm
Steller's jay	tree branch	—
Common raven	probably soil	?
Red squirrel	soil	6.5 - 40 cm
Douglas squirrel	probably soil	?
Chipmunk	soil	probably >20 cm (?)
Golden-mantled ground squirrel	soil	?

thermal and reproductive cover in an otherwise inhospitable environment. And all this ultimately goes back to Clark's nutcrackers—caching the seed of whitebark pine in a manner that leads to successful establishment of seedlings.

SUMMARY

Whitebark pine depends upon animal dispersal for regeneration. There are many dispersal agents of whitebark pine seed, but only a few promote whitebark pine seedling establishment (table 5). The preponderance of evidence lies in favor of Clark's nutcracker—which by itself is almost entirely responsible for whitebark pine regeneration. These long-distance dispersal agents should be the key focus in subalpine community management.

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RED SQUIRRELS IN THE WHITEBARK ZONE

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ABSTRACT

Reports results of a study of interactions among red squirrels (Tamiasciurus hudsonicus), *bears* (Ursus *spp.*), *and whitebark pine* (Pinus albicaulis) *from 1984 through 1987 in north-central Yellowstone National Park and in the vicinity of Cooke City, MT. This paper deals with results that pertain to habitat relationships of red squirrels in the whitebark pine zone. Indices of red squirrel activity and abundance were highest in the mesic and wet habitat types. Pure whitebark pine stands were apparently not favorable habitat for red squirrels. In the whitebark pine zone, cones of other conifer species were needed to offset yearly variations in whitebark pine cone production. Optimal red squirrel habitat in this zone consisted of stands with high tree species diversity, basal area, and environmental favorability. Annual fluctuations in red squirrel densities reflected yearly whitebark pine cone production in stands with a high whitebark pine component. Bears may play a role in regulating red squirrel abundance in whitebark pine stands.*

INTRODUCTION

Red squirrels (*Tamiasciurus hudsonicus*) are commonly associated with coniferous forests. They range extensively in the boreal regions of North America from Alaska to Arizona and from northern Quebec to the Appalachian Mountains (Smith 1970). Red squirrels are typically diurnal, solitary, and active throughout the year. Their diet consists primarily of the reproductive products of trees, fungi, and shrubs within the forests they occupy (C. Smith 1968). Although red squirrels are well adapted to live on a variety of foods available during the growing season (Ferron and others 1986), in the Rocky Mountains they must rely on stored conifer seeds for half the year (Finley 1969; Rusch and Reeder 1978). Conifer seed cones represent storable, high-energy packages that are relatively resistant to spoilage (Weigl and Hanson 1980).

Red squirrels subsist on a seasonal food supply on a year-round basis by caching and storing conifer seed cones gathered within established, defended territories. Gathering and storing cones occupy up to 80 percent of their daily activity from August through November (C. Smith 1968). Individual territories are nonoverlapping and contiguous within forest habitats and are defended from other red squirrels regardless of sex by vocalizations and by chasing intruder squirrels (Rusch and Reeder 1978; C. Smith 1968).

A large, centralized midden is a major feature of a red squirrel territory. Middens are sites traditionally used to cache and feed on cones and consist of large amounts of cone clippings. They occasionally extend into springs, bogs, and creek bottoms where added moisture helps preserve cones in a closed, more storable condition (Finley 1969).

In high-elevation mountain forests of western North America, whitebark pine (*Pinus albicaulis*) trees produce annually fluctuating crops of large, edible seeds (Forcella and Weaver 1986). These seeds are extensively used by wildlife such as Clark's nutcracker (*Nucifraga columbiana*), bears (*Ursus* spp.), and red squirrels (Kendall 1981; Tomback 1982). The large, edible seeds of whitebark pine are apparently preferred over other conifers by red squirrels and are readily cached when available (Hutchins and Lanner 1982). Whitebark pine seeds are also an important fall and spring food for grizzly bears (*Ursus arctos*) within the Yellowstone ecosystem and are obtained almost exclusively by raiding squirrel caches (Kendall 1981). During 1984 through 1987 the Interagency Grizzly Bear Study Team (IGBST) studied the interrelationships of grizzly bears, red squirrels, and whitebark pine. Habitat relationships of red squirrels within the whitebark pine zone are presented here.

STUDY AREA

Our study area consisted of the Mount Washburn massif in north-central Yellowstone National Park, and an area in the Gallatin National Forest near Cooke City, MT (fig. 1). Both areas were located in higher elevations of the subalpine zone on moderately steep topography. Elevations ranged from 2,360 m (7,800 ft), just below the lower elevational limits of whitebark pine distribution, to 2,865 m (9,400 ft) at the upper limits of erect tree growth.

Most study area timber cover was mature to overmature with some stands of pole-sized, even-aged trees. Whitebark pine occurred throughout the study area and was variously represented from dominant to scattered individuals. Whitebark pine was more prevalent in the Mount Washburn area than in the Cooke City area, where lodgepole pine (*Pinus contorta*) was a more common dominant.

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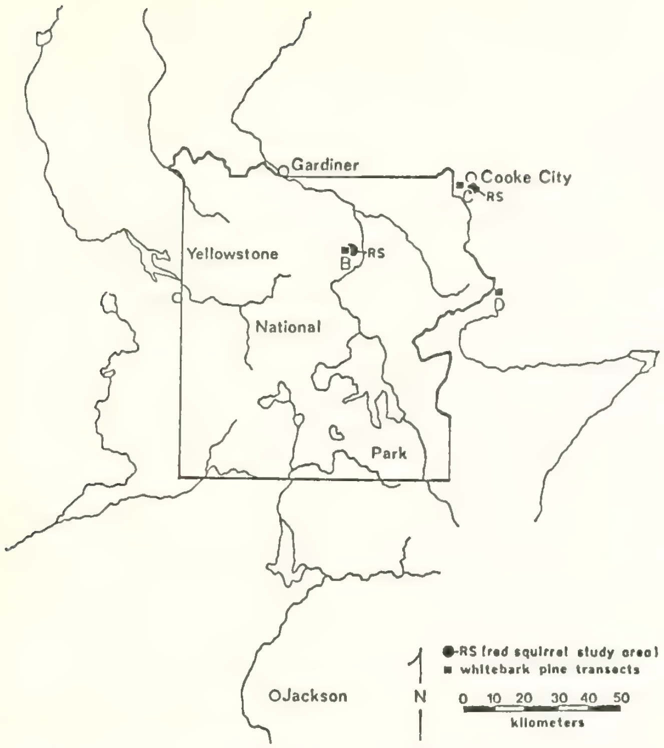

Figure 1—Location of red squirrel study areas (RS) and whitebark pine transects: Mount Washburn (B) and Cooke City (C).

The study area included five major habitat types described by Steele and others (1983). The *Pinus albicaulis* (PIAL) series habitat types prevailed at high elevations on west and south aspects. The *Abies lasiocarpa/Vaccinium scoparium-Pinus albicaulis* (ABLA/VASC-PIAL) and *Abies lasiocarpa/Vaccinium globulare-Vaccinium scoparium* (ABLA/VAGL-VASC) habitat type phases were the most common habitat types in our study area. The *Abies lasiocarpa/Vaccinium scoparium-Vaccinium scoparium* (ABLA/VASC-VASC) phase, *Abies lasiocarpa/Thalictrum occidentale* (ABLA/THOC), and *Abies lasiocarpa/Spiraea betulifolia* (ABLA/SPBE) habitat types occurred at low elevations. The wet site *Abies lasiocarpa/Calamagrostis canadensis* (ABLA/CACA) type was found near creek bottoms and seeps.

METHODS

We delineated homogeneous timber stands on USGS 15-ft topographic maps and 1:20,000 and 1:30,000 color aerial photographs. Line transects were laid out to intercept all stands so that no transects intersected and stand edge effect was minimized. Transects were laid out without bias toward timber stands or toward the monitored squirrel population. Transect lengths were determined from airphotos and corrected for slope.

Field work was conducted from mid-August to mid-September from 1984 through 1987. Beginning and end points were located using airphoto interpretation and marked with stakes. Two people walked all transects each year during daylight hours; one person maintained compass bearing and distance pacing, while the other person was responsible for observing and recording squirrel sign. Regular pauses were observed every 100 to 200 m in each stand for habitat evaluation.

All stands were identified by forest habitat type (Steele and others 1983) and forest cover type (Despain 1977; Mattson and Reinhart, this proceedings). In addition, between 5 and 26 systematically placed variable-radius overstory plots were taken in each stand (see Mattson and Reinhart, this proceedings).

Red squirrel data were collected annually while walking line transects (see Eberhardt 1978). Squirrel sign was referenced to transect locus and perpendicular distance from transect. All unduplicated sightings or vocalizations discerned from the transects and estimated to be within stand bounds were recorded. All individual squirrel middens observed from transects were noted and described as active or inactive based on the presence of cached cones, fresh cone clippings, or squirrels. Red squirrel activity was recorded between 0 to 60 m from transect lines. Bear activity and bear-excavated red squirrel middens were also noted.

We calculated two indices of relative squirrel abundance for habitat types and for habitat type-cover type combinations. We summed sightings and vocalizations and divided by total transect length to derive linear frequency of occurrence. Similarly, we divided total middens by transect length to derive linear frequency of middens.

Annual whitebark pine cone production for Cooke City and Mount Washburn study areas was obtained by counting cones on marked trees along predetermined whitebark pine cone transects (Blanchard, this proceedings).

RESULTS

Data were collected on up to 50 km of line transects per study year. Between 41 and 57 transects that sampled between 40 and 74 stands were walked annually on Mount Washburn. Between 15 and 22 transects surveyed between 51 and 65 stands near Cooke City.

Annual whitebark pine cone production varied widely in the study areas (fig. 2). Whitebark pine cone production was highest in 1985 and lowest in 1986. Cone crops in 1984 and 1987 were intermediate. Cooke City cone data were missing in 1984 and therefore extrapolated using simple linear regression. Actual cone production in 1987 was believed to be higher than the cone counts indicated because of earlier than normal cone maturation and harvest and late cone surveys (Blanchard, this proceedings).

Several patterns were evident by linear counts of vocalizations plus sightings and active middens (table 1, fig. 3):

1. Relatively little squirrel activity occurred in PIAL series habitats on Mount Washburn. These were mostly pure near-climax whitebark pine stands.

2. Moderate amounts of squirrel sign were found on the drier ABLA/SPBE type and in the ABLA/VASC-PIAL phase.

3. A higher incidence of red squirrel activity occurred in more mesic habitats represented by the ABLA-THOC habitat type and the ABLA/VAGL-VASC and ABLA/VASC-VASC phases and in the wetter sites of the ABLA/CACA habitat type.

We calculated annual variation of squirrel density indices for the major study area habitat types (table 1). On Mount Washburn (fig. 3A), annual variation in squirrel abundance generally reflected annual variation in whitebark pine cone production. This pattern was most evident in the ABLA/VASC-PIAL phase but was also apparent in the other more mesic habitat types. At Cooke City (fig. 3B), sequential years' variation of squirrel densities was not as pronounced as on Mount Washburn with the exception of the ABLA/VASC-PIAL phase where variation did reflect the whitebark pine cone crop.

There were differences in the extent of variation among years between the two indices used to measure squirrel abundance (fig. 3). Linear densities of vocalizations and sightings varied more than linear densities of active middens. There was also an exponential increase in the density of vocalizations plus sightings relative to the increase in the density of active middens ($r^2 = 0.959$, $P < 0.001$) (fig. 4).

Average linear frequency of middens for different habitat types was positively related to average timber basal area ($r^2 = 0.675$, $P < 0.001$) (fig. 5). The ABLA/VASC-PIAL habitat type-whitebark pine cover type deviated the most from this relationship. Lodgepole pine cover types of the ABLA/VASC-PIAL phase fit the general relationship of basal area and squirrel density. At an average basal area of less than 67.7 m^2/ha (90 ft^2/acre), no resident squirrels occurred. Mean basal area for the PIAL series defined this extreme end point.

We also related a synthetic environmental variable, "site favorability," to mean squirrel midden abundance (fig. 6). Site favorability was an index that positively weighted direct solar radiation and negatively weighted wind exposure and elevation. Mattson and Reinhart (this proceedings) more fully described this variable. Squirrel abundance was lowest on the coldest, highest, and most wind-exposed habitat types ($r^2 = 0.792$, $P < 0.001$). Variation from this relationship was associated with overstory species diversity and higher basal areas of whitebark pine and Douglas-fir (*Pseudotsuga menziesii*). Habitat types with less squirrel densities included the PIAL series, which consisted of almost pure whitebark pine stands, and the ABLA/VASC-VASC phase, which consisted of predominantly pure lodgepole pine stands. The lodgepole pine cover type of the ABLA/VASC-PIAL phase and the ABLA/SPBE habitat type showed higher squirrel densities than expected by site favorability index. Higher levels were associated with moderate overstory diversity and relatively high basal areas of whitebark pine and Douglas-fir, respectively.

Table 1—Mean densities (n/km) and coefficients of yearly variation of active red squirrel middens for habitat types of the two study areas

	Midden density			
	Mount Washburn		Cooke City	
Habitat type	$\bar{x}$	C.V.	$\bar{x}$	C.V.
ABLA/CACA	3.64	0.506	2.35	0.719
ABLA/THOC	3.20	0.233	1.63	0.355
ALBA/VAGL-VASC	2.60	0.079	1.92	0.250
ABLA/VASC-VASC	2.78	0.243	—	—
ABLA/VASC-PIAL, LP cover type	3.80	0.389	4.34	0.737
ABLA/VASC-PIAL, WB cover type	1.15	0.548	1.38	0.188
ABLA/SPBE	1.53	0.580	—	—
PIAL series	0.11	0.200	—	—

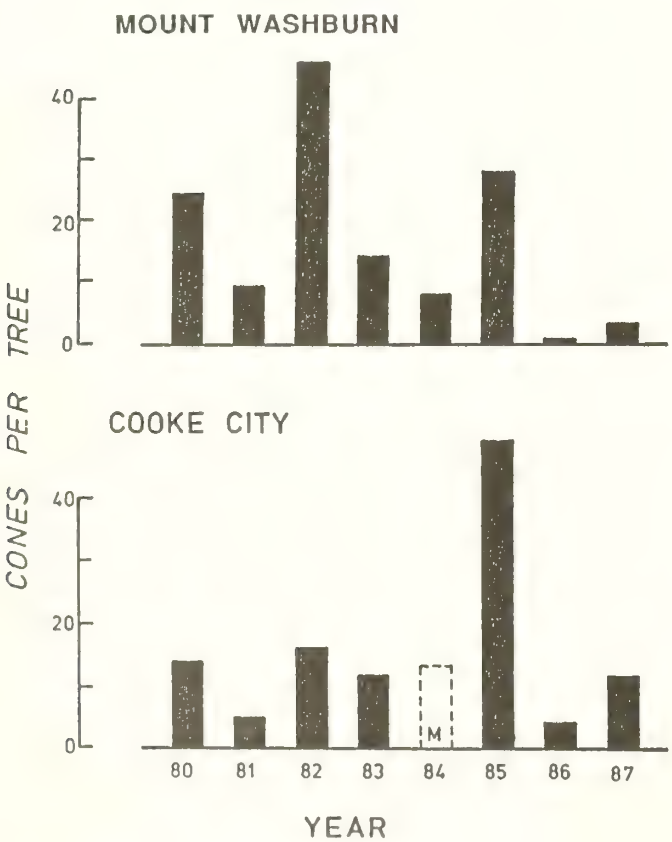

Figure 2—Whitebark pine cone production, 1980-1987, for the Mount Washburn and Cooke City study areas. Cone production for Cooke City in 1984 was extrapolated.

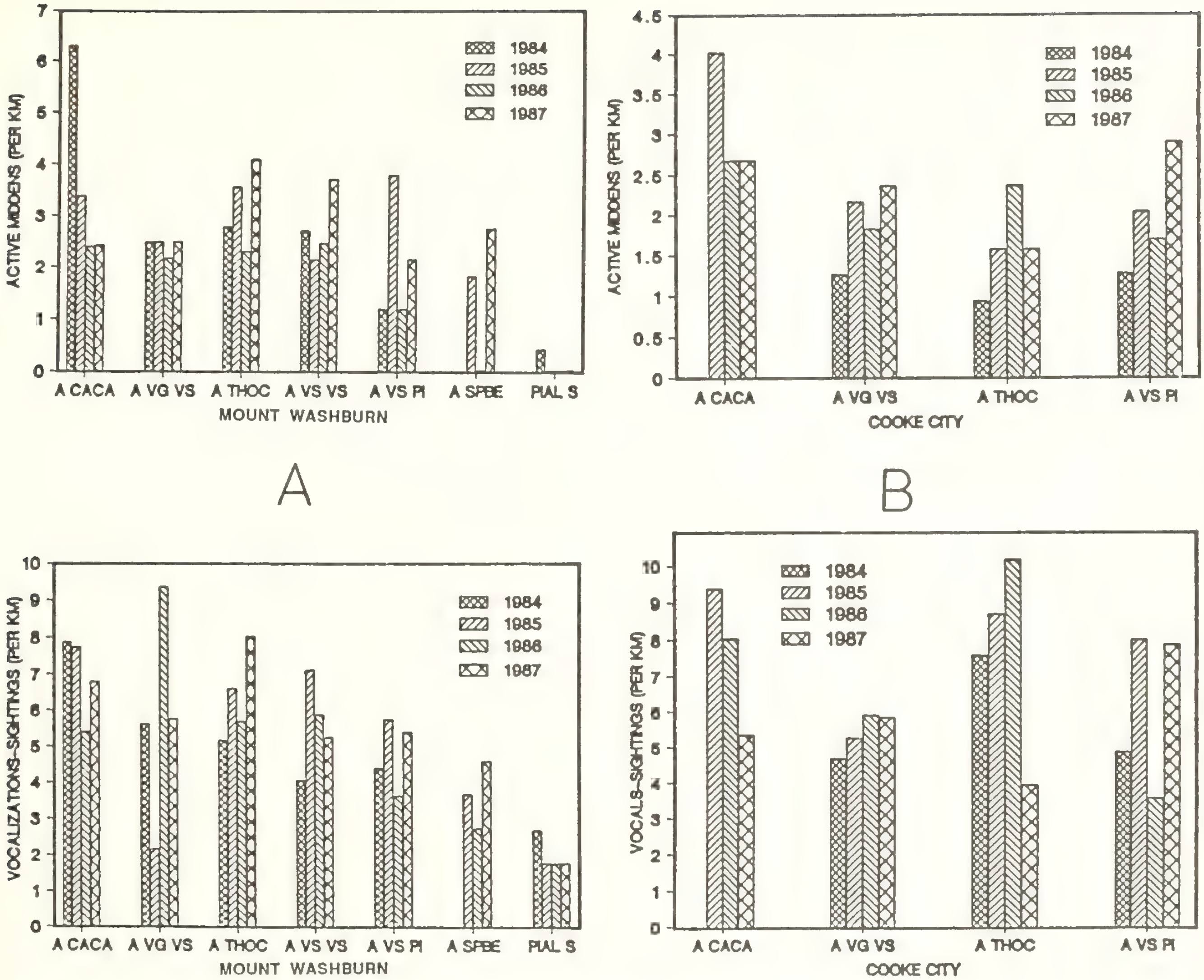

Figure 3—Linear densities of active squirrel middens and sightings + vocalizations for habitat types in the Mount Washburn (A) and Cooke City (B) study areas, 1984-1987.

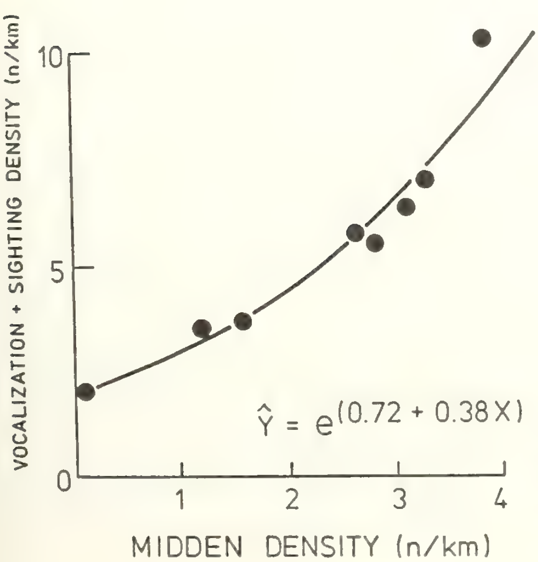

Figure 4—Relationship of average linear densities of squirrel middens and vocalizations + sightings for the Mount Washburn study area. Densities were averaged by habitat type and by habitat type and cover type for the ABLA/VASC-PIAL h.t.

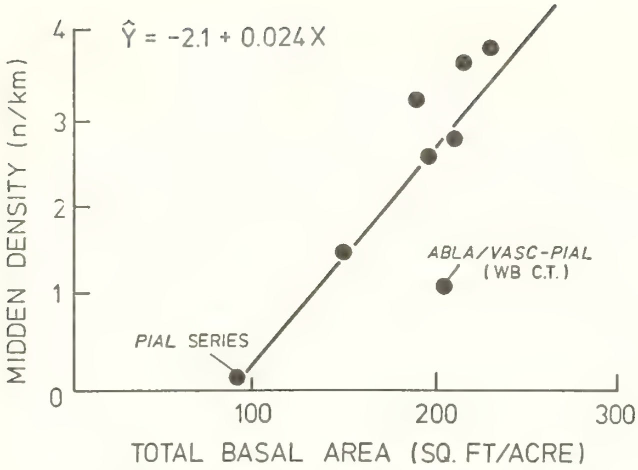

Figure 5—Relationship of active midden density and total timber basal area for the Mount Washburn study area.

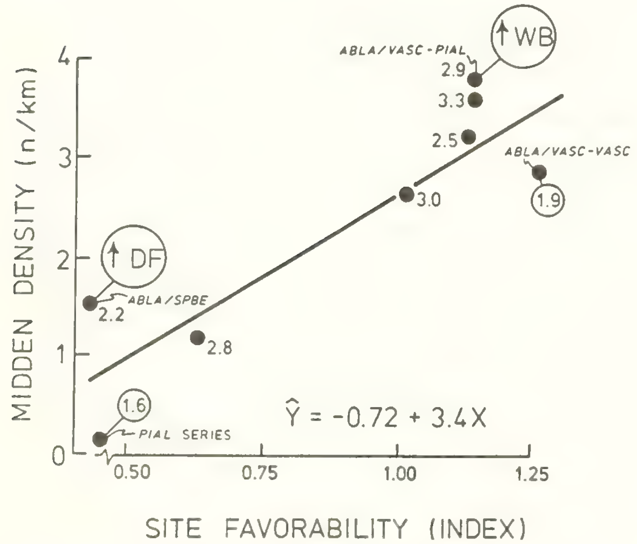

Figure 6—Relationship of active squirrel midden density and site favorability index for the Mount Washburn study area. Numbers at each datum are overstory diversity (e^{H}; Shannon and Weaver 1963) for the corresponding type.

DISCUSSION

Line transects have been used in previous studies to describe the relative abundance of wild populations (Burnham and others 1980; Eberhardt and others 1979; Hayne 1949). Indirect evaluation techniques have been useful measures of animal abundance when used to compare data between areas and time periods, or to associate habitat parameters with wildlife populations (Halvorson 1984). The following criteria should be met to reduce bias and variability in auditory and visual line transects of red squirrels (Eberhardt 1978; Halvorson 1984; Hayne 1949):

1. Sample design includes standardized methods that are repeatable.
2. Transects are laid out without bias toward the monitored population.
3. Time of day or season in relation to animal activity patterns does not vary over the course of the sampling period.
4. The effects of topography and cover on animal response to the observer are known.
5. Monitoring of a population is undertaken for a time period long enough to cover full cycles of population abundance.

This study of red squirrel populations appeared to have met these criteria. Red squirrel vocalizations could be heard between 0 to 60 m from transect lines, and usually occurred when the observer entered a red squirrel territory (C. Smith 1968). Red squirrels and middens were sighted between 0 to 40 m from the transect lines. There were no apparent differences in the frequency of squirrel calls or sightings related to time during daylight hours; stand boundaries and red squirrel territories were discrete so that topography changes were not critical to our evaluation. This study encompassed 4 years that included high, low, and intermediate whitebark pine cone crops. Although more years are needed to fully monitor red squirrel population trends (Halvorson 1984), some aspects of red squirrel habitat relationships can be addressed.

The high correlation of vocalization plus sighting densities with midden densities suggests that these two indices reflected the same phenomenon, and tends to corroborate the validity of each as a measure of squirrel abundance. The greater frequency of vocalization plus sighting densities relative to midden densities could have been a reflection of our greater sensitivity to red squirrel activity because of the greater detection range of vocalizations relative to middens. The exponential increase and greater variation of vocalizations and sightings with respect to middens could also reflect positive acoustical feedback similar to ruffed grouse (*Bonasa umbrellus*) behavior (Rogers 1981). With increasing squirrel densities (midden densities), there could have been an exponential increase in vocalizations triggered as a positive response to one squirrel's initial call. We suspect that this second explanation holds, and so considered squirrel midden abundance to be a more reliable indicator of squirrel density in our study area.

The whitebark pine zone apparently constitutes an extreme of the red squirrel niche. Pure whitebark pine stands, represented by the PIAL series habitat types, were not hospitable habitats for red squirrels. Factors that may contribute to the lack of red squirrels in pure whitebark pine stands include less total overstory basal area and species diversity, highly variable cone crops characteristic of whitebark pine, and the high, cold, harsh environments associated with these stands. The more mesic and wetter habitat types supported more red squirrels. These habitats had more overstory diversity, which in turn offered red squirrels other species' cone crops when whitebark pine seeds were not available. Lodgepole

pine was an important conifer species to red squirrels. Although less preferred by red squirrels compared to some other tree species (Finley 1969), lodgepole pine played an important role in red squirrel habitat by providing a more consistent source of serotinous and thus more storable cones (C. Smith 1968).

Annual variation in red squirrel densities apparently reflected general whitebark pine cone crops in stands with a moderate to high proportion of whitebark pine. This was most evident in the ABLA/VASC-PIAL phase of both the Cooke City and Mount Washburn study areas. Although cone crops of other conifer species in mixed stands were not measured in this study, they apparently played an important role in the red squirrels' food supply, especially in years of poor whitebark pine cone mast (Finley 1969). In general, squirrel densities in all habitat types were more sensitive to whitebark pine crops in the Mount Washburn study area where whitebark pine was more prevalent than in the Cooke City study area. Two factors may explain greater yearly fluctuations in red squirrel densities in stands with a substantial amount of whitebark pine:

1. The food supply associated with large whitebark pine cone crops may allow the temporary establishment of more territories and squirrels in areas that did not previously support red squirrels.
2. Bear depredation of red squirrel caches may compound the effects of variable whitebark pine crops by further disrupting the squirrel population social status, by competing for food, and by occasionally eating red squirrels outright. Squirrel remains show up in grizzly bear scats containing whitebark pine seeds (Knight and others 1987).

Regulatory factors have been identified for red squirrel populations in other study areas. C. Smith (1968) suggested that territoriality allowed individual red squirrels the optimum conditions for harvesting, storing, and defending a seasonal food supply throughout the year. He further demonstrated that territory size was related to food supply, or was inversely proportional to habitat quality. Kemp and Keith (1970) found a strong correlation between white spruce (*Picea glauca*) cone crops and red squirrel population levels. However, M. Smith (1968) showed that red squirrel populations could survive a white spruce cone crop failure by caching surplus cones during good mast years.

Red squirrel populations in our study areas may be influenced by bear use and flexible habitat requirements of squirrels. Our study area included the edge of occupied red squirrel habitat. In the whitebark pine zone this edge varied with whitebark pine cone production. In years of unusually large whitebark pine crops, red squirrels occupied pure whitebark pine stands (Kendall 1981). However, this occupancy was probably shortlived. We found little sign of permanent red squirrel occupancy in stands with a high percentage of whitebark pine. Generally, with increased site favorability and species diversity, middens were characterized by increasing amounts of cone debris that indicated a longer history of occupancy. Red squirrels apparently established transient territories in whitebark stands during years of large cone crops because of the high forage quality of whitebark pine seeds. We are not sure how this was realized, but it was probably by the immigration of juveniles or extension of ranges by established squirrels into adjacent whitebark pine stands. Squirrels probably do not survive poor mast years in nearby pure whitebark pine stands because of frequent poor crops, the lack of alternative foods, and depredations by bears that possibly deprive them of an additional year's food. Ognev (1940) described a similarly dynamic situation for the European squirrel (*Sciurus vulgaris*) in the range of Asian stone pines (subsection Cembrae). He described transient territories and even mass "migrations" following years of crop failures.

More research is needed to better understand the relationships among whitebark pine, red squirrels, and bears, as well as how specific silvicultural treatments affect this system. Longer term study is required to assess red squirrel population responses to variable whitebark pine cone crops. In mixed and pure whitebark pine stands, red squirrel densities should be monitored, as should cone mast of all conifer species stratified by age and size classes. Study of red squirrel territory sizes with respect to different habitats or whitebark pine crops, as well as territory stability with respect to site favorability would provide valuable insight into red squirrel population regulation in this zone. More data are needed to assess the interaction between bears and red squirrel populations in the whitebark pine zone. This may be approached by relating levels of midden use by bears to annual variations in red squirrel densities and whitebark pine cone crops.

MANAGEMENT IMPLICATIONS

Timber management can potentially affect red squirrel population densities in the whitebark pine zone. Whitebark pine is not considered to be a valued commercial timber species (Arno and Hoff 1989). However, timber harvests do occur in stands that contain whitebark pine, primarily in stands of higher commercial value in the lower part of whitebark pine's elevational distribution. Basal area reduction by timber harvest in the whitebark pine zone will almost certainly reduce squirrel densities. Our results suggest this effect. Other studies in Alaska (Wolf and Zasada 1975) and Ohio (Nixon and others 1980) have also documented reduction in squirrel densities following reduction in basal area of seed-producing trees.

The strong link between red squirrels and grizzly bears (Kendall 1981; Mattson and Jonkel, this proceedings) in the whitebark pine zone merits the attention of resource managers. Management of grizzly bear habitat in the whitebark pine zone is partly contingent on management of red squirrel habitat and populations. Because of squirrel habitat requirements, management for both bears and squirrels logically revolves around maintenance of diverse-species, high-basal-area stands on favorable, more mesic sites of the zone. Forest managers should be cautious when applying silvicultural practices in whitebark pine forests to "enhance" grizzly bear habitat. Leaving seed-bearing

whitebark pine trees in shelterwood cuts would reduce red squirrel densities by reducing overstory diversity and basal area. Planting whitebark pine seedlings following clearcutting may benefit long-term management of these stands, but will have little positive effect until these slow growing trees are mature enough to bear cones. Both practices would increase human access and activity. Increased risk of bear displacement and mortality would outweigh any gains achieved by overt forest manipulation.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from Ron Lanner)—How many years is a squirrel midden likely to remain active?

A.—Middens of cone scales and cores in addition to cached cones are conspicuous signs of a red squirrel territory. They range in size from 1 to 300 m^2. Large middens can be decades old and represent the accumulation of many successive generations of red squirrels (Finley 1969). The advantage of a long-used, traditional site midden is that stored cone clippings help maintain cached cones in a moist, more storable condition.

Midden use is apparently short lived in predominant whitebark pine stands compared to other more diverse sites. Active middens can be recognized from inactive middens by the presence of fresh cones, cone clippings, and red squirrels at midden sites. In the predominant whitebark pine stands, we found active middens were generally smaller and newer than in other more mesic habitats. The proportion of all encountered middens found to be inactive was also higher in stands with a higher whitebark pine component. This may represent higher annual fluctuations in red squirrel abundance. This is consistent with our findings that pure whitebark pine stands are not favorable habitats for red squirrels.

WHITEBARK PINE—AN IMPORTANT BUT ENDANGERED WILDLIFE RESOURCE

Katherine C. Kendall
Stephen F. Arno

ABSTRACT

Whitebark pine (Pinus albicaulis) *is a valuable wildlife resource in the western United States and southwestern Canada. Its large seeds are a preferred food for a variety of birds and mammals, especially Clark's nutcrackers* (Nucifraga columbiana), *red squirrels* (Tamiasciurus hudsonicus), *and bears* (Ursus *spp.). Whitebark pine communities provide food and shelter for nongranivorous species as well.*

In many areas, whitebark pine populations are being depleted by advancing forest succession and insect and disease epidemics. Extensive but unknown numbers of whitebark pine were lost to mountain pine beetle (Dendroctonus ponderosae) *in the Intermountain West in the 1970's and early 1980's. Dwarf mistletoe* (Arceuthobium *spp.) is a significant source of mortality in some parts of California, Oregon, Nevada, and Wyoming. White pine blister rust* (Cronartium ribicola) *has killed much of the whitebark pine in portions of the Inland Northwest.*

This paper summarizes available information on the status and health of whitebark pine and on its importance to wildlife. Widespread losses of this species have a variety of implications for management issues such as the restoration of grizzly bear (U. arctos horribilis) *populations. The need for better information on the status of whitebark pine is discussed.*

INTRODUCTION

Whitebark pine (*Pinus albicaulis*) is a valuable resource for a variety of birds and mammals in the western United States and southwestern Canada. Its large, wingless seeds are a preferred, high-energy food source, and whitebark communities provide other foods and shelter for several wildlife species inhabiting a harsh environment. The importance of whitebark pine to wildlife, however, has only recently been recognized. While useful research on red squirrels (*Tamiasciurus hudsonicus*), Clark's nutcrackers (*Nucifraga columbiana*), and bears (*Ursus* spp.) in whitebark pine communities has been conducted in the last decade, information is scarce on many aspects of wildlife ecology in these forests.

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Recently, Arno (1986) warned that whitebark pine appears to be threatened by the effects of fire suppression and insect and disease epidemics. Because whitebark pine occupies cold, high-elevation sites, it grows and matures very slowly. Most trees are about a century old before they produce significant cone crops. Thus, whitebark pine stands are especially slow to recover from damage and slow to respond to management measures. In this paper, we summarize currently available information on the status and health of whitebark pine (little of which is published) and on the importance of whitebark pine to wildlife.

IMPORTANCE TO WILDLIFE

Whitebark pine forests appear to be significantly more productive, in terms of mass of seed produced per unit area, than most other temperate coniferous forests (Forcella 1977). The importance of whitebark pine as a wildlife food arises from the large size (0.1 to 0.2 g/seed; Krugman and Jenkinson 1974; McCaughey and Schmidt, this proceedings) and high lipid content (78 percent; Mealey 1980) of its seeds. The seeds are a concentrated, high-quality food source that can be stored for 12 months or more in squirrel middens or nutcracker caches; other high-elevation foods are more ephemeral. Typically, birds and mammals harvest almost all the viable seeds produced.

Red squirrels concentrate their foraging activities on whitebark pine seeds when they are available, virtually ignoring other foods. They are the most efficient of all whitebark pine seed predators because they can cut down and cache cones quickly. Squirrels also guard their caches from most other seed harvesters except bears. In a mixed stand of whitebark pine in Squaw Basin, WY, red squirrels accounted for 63 percent of all whitebark pine seeds taken by vertebrates (Hutchins and Lanner 1982). However, in nearly pure stands of whitebark pine, squirrel densities tend to be low (Mattson and Reinhart 1987) and Clark's nutcrackers harvest most of the seeds. Apparently, squirrel populations are highest where mature whitebark pine is mixed with other conifers. In these stands, alternate foods are available during years of low whitebark pine cone production.

Whitebark pine cones do not open and fall from the tree upon ripening in September. Cones are available to bears in some areas on stunted trees. Typically, however, bears obtain seeds from squirrel caches. The whitebark pine stands that are most valuable to bears, then, are those inhabited by large populations of red squirrels.

Whitebark pine seeds are an important autumn food for grizzly (*U. arctos*) and black (*U. americanus*) bears wherever whitebark pine is common in Montana and Wyoming. This has been confirmed for the Whitefish Range (Tisch 1961), East Front of the Rocky Mountains (Aune and Kaseworm in preparation), Scapegoat Wilderness (Craighead and others 1982), and Yellowstone National Park (Knight and others 1988).

Whitebark pine seed consumption by grizzly bears in the Yellowstone area is closely correlated with cone crop size (Knight and others 1988). During good cone crop years, Yellowstone bears feed almost exclusively on pine seeds in autumn (Knight and others 1985). Furthermore, seeds from the exceptionally heavy 1978 cone crop were the dominant bear food consumed in the spring and summer of 1979 (Kendall 1983). Good cone crops appear to be positively correlated with grizzly bear cub production and early weaning of young (Blanchard 1989; Knight 1989); poor whitebark pine cone crops are associated with increased grizzly bear mortalities and conflicts with humans (Knight and others 1988).

In the Soviet Union, brown bears (*U. arctos*) feed on the seeds of the closely related Siberian stone pine (*P. sibirica*). During years of massive cone crop failure, large numbers of emaciated bears make long migrations in search of food, frequently entering villages and killing livestock and occasionally attacking people (Pavlov and Zhdanov 1972; Ustinov 1972).

The Clark's nutcracker has evolved mutualistic relationships with pines that have large, wingless seeds. Whitebark pine is a preferred food for the nutcracker which, in turn, is responsible for most whitebark pine dispersal and regeneration. Nutcrackers cache seeds up to 14 mi away from a seed source (Vander Wall and Balda 1977). They bury more whitebark pine seeds than they require for winter and spring food, and many seed caches are in sites suitable for whitebark pine establishment (Tomback 1982). Nutcrackers are so dependent on whitebark pine and other conifer seeds that years of widespread cone crop failure cause nutcracker irruptions in which the birds may move hundreds of miles from their normal range (Davis and Williams 1964). Use of pine seed caches to feed nestlings and fledglings enables Clark's nutcrackers to nest earlier than other passerines, which must wait until insects are available for feeding. By the next winter, the more mature and experienced nutcracker offspring may be better able to survive (Tomback 1978).

Other birds and mammals are relatively minor consumers of whitebark pine seeds compared to the species discussed above (Hutchins and Lanner 1982; Tomback 1978). Golden-mantled ground squirrels (*Spermophilus lateralis*) and several species of chipmunk (*Eutamias* spp.) harvest seed from cones on the ground. Chipmunks also gather seed from cones in trees. The following birds are reported to feed on whitebark pine seeds: hairy and white-headed woodpeckers (*Picoides villosus* and *P. albolarvatus*), Williamson's sapsucker (*Sphyrapicus thyroideus*), mountain chickadee (*Parus gambeli*), white- and red-breasted nuthatches (*Sitta carolinensis* and *S. canadensis*), Steller's jay (*Cyanocitta stelleri*), raven (*Corvus* spp.), pine grosbeak (*Pinicola enucleator*), red crossbill (*Loxia curvirostra*), and Cassin's finch (*Carpodacus cassinii*).

The significance of whitebark pine to wildlife extends beyond its seeds as food. Its community structure is also valuable to wildlife. The openness and influence of fire in some whitebark pine stands provide conditions for abundant wildlife forage. Whitebark pine will grow in high-elevation, exposed sites where it modifies the microclimate and allows other less hardy vegetation to establish (Habeck 1969; Snethen 1980). In winter, blue grouse (*Dendragapus obscurus*) often roost at timberline in the dense protective crown of whitebark pine, which provides thermal and hiding cover. The grouse also feed on whitebark pine buds and needles (Arno 1970). Cavities in whitebark pine snags provide favored nest sites for mountain bluebirds (*Sialia currucoides*) and northern flickers (*Colaptes auratus*) (McClelland 1989).

Significant reductions in whitebark pine cone production may lower the wildlife carrying capacity of an area. Fewer whitebark pine seeds should result in fewer seed consumers and a decline in the number of their predators. Bears are both primary and secondary consumers in this system; they feed directly on pine nuts and on animals, such as red squirrels, that preferentially feed on pine nuts. In areas where whitebark pine is a major forest component, bears have been implicated as a factor in regulating red squirrel populations (Mattson and Reinhart 1987). Grizzly bears also prey on ungulates, especially elk (*Cervus canadensis*) calves (French and French in press). Because grizzly bear reproductive and mortality rates are correlated with whitebark cone crops in Yellowstone, long-term declines in cone production may lower bear population levels and could result in a decline in ungulate predation.

THREATS TO WHITEBARK PINE

Insect and disease epidemics and successional replacement by other conifers have reduced the numbers of whitebark pine throughout its range in the last 80 years (Arno 1986). In most communities (mixed stands) where whitebark pine provides food for squirrels and bears, it is a seral species perpetuated primarily by fire. Fire suppression has favored shade-tolerant conifers. Prior to the early 1900's, average natural fire intervals for whitebark pine stands were 50 to 350 years (Arno and Weaver, this proceedings; Morgan and Bunting, this proceedings), but under current management policies a seral whitebark pine stand would burn at 3,000-year intervals (Arno 1986).

Fire control has apparently increased the damaging effects of mountain pine beetle (*Dendroctonus ponderosae*) and dwarf mistletoes (*Arceuthobium* spp.), all native species, on whitebark pine. Even without the effects of fire suppression, mountain pine beetle epidemics killed large numbers of whitebark pine between 1909 and 1940 in Idaho and Wyoming (Arno 1970). With fire control, however, more extensive areas of old lodgepole pine (*P. contorta*) have developed. These support severe mountain pine beetle epidemics that spread to higher elevations and result in greater whitebark pine mortality than under natural fire regimes. Mountain pine beetles can also cause more mortality in the older whitebark pine stands that result from fire suppression.

Because dwarf mistletoe is controlled by stand-replacing fire, it is now more prevalent in undisturbed stands than in the past (Alexander and Hawksworth 1976). Whitebark pine is a principal host of limber pine dwarf mistletoe (*A. cyanocarpum*) and is heavily parasitized by leafless mistletoe (*A. americanum*) (Jackson and Faller 1973; Mathiasen and Hawksworth 1988). Both can reduce growth rates of heavily infected hosts, increase mortality rates, reduce seed and cone production, and increase vulnerability to other diseases and insects (Hawksworth and Wiens 1972).

White pine blister rust (*Cronartium ribicola* Fisch.), native to Europe, was accidentally introduced to western North America in 1910 and has since infected whitebark pine throughout its range (Hoff and Hagle, this proceedings). It attacks all North American five-needled pines, but whitebark pine is the most susceptible (Hoff and others 1980). The disease often first kills the upper, cone-bearing branches, and can eventually kill the entire tree. Seedlings and saplings are readily infected. Thus, white pine blister rust can significantly decrease whitebark pine seed production and regeneration (Arno and Hoff 1989). Blister rust infection also makes trees more susceptible and attractive to other diseases and insects, including mountain pine beetle. Blister rust control efforts, begun in the late 1930's, were largely unsuccessful and were abandoned in the 1970's.

Fires in whitebark pine stands normally are beneficial to regeneration of the species. Some large, severely burned areas, however, have failed to regenerate whitebark pine (fig. 1). The proposed Great Burn Wilderness in the Clearwater National Forest in northern Idaho, and the Lolo National Forest in western Montana supported extensive ridgetop stands of whitebark pine that were burned by the severe Great Idaho Fire in 1910 (Cohen and Miller 1978). Recent reconnaissance (by Arno) in different parts of this old burn revealed little or no regeneration of whitebark pine on sites (above 6,500 ft; 1,980 m) where snags confirm that it was once a dominant species. Other subalpine conifers have become reestablished (fig. 2). Two plausible explanations for the negligible reestablishment of whitebark pine are: (1) inadequate whitebark pine seed source survived the 1910 fire and (2) white pine blister rust has killed most of the seedlings and much of the seed source.

Moderate levels of whitebark pine mortality may benefit some species of wildlife. Mortality from mountain pine beetle, mistletoe, and blister rust opens the forest canopy. This may result in increased undergrowth vigor and forage production. For instance, berry production is often negatively correlated with canopy closure. Forcella (1977) studied the productivity of 28 stands in the *P. albicaulis-Vaccinium scoparium* association with varying amounts

Figure 1—Remains of a nearly pure whitebark pine stand killed in the Great Idaho Fire of 1910. Site is in the upper subalpine zone (Pfister and others 1977); the poorly developed postfire regeneration is composed of lodgepole pine and subalpine fir. Scene is at about 7,300 ft (2,225 m) elevation on Granite Peak, on the Idaho-Montana divide 8 air miles northwest of Lolo Pass. (Photo by S. Arno.)

Figure 2—Along the Idaho-Montana divide 7 miles northwest of figure 1 (west of Kid Lake). Large snags are mostly whitebark pine that survived a low-intensity fire in the mid-1800's but were killed in the severe 1910 fire. Regeneration of subalpine fir and lodgepole pine has been successful at the more moderate elevations in the foreground (about 6,500 ft; 1,980 m); but very little regeneration has taken place above 7,000 ft (2,130 m) (background) where nearly pure whitebark pine groves formerly existed. (Photo by S. Arno.)

of tree canopy cover. He identified three significant wildlife foods other than pine nuts: *V. scoparium* berries, *Carex geyeri*, and *Arnica* spp. He found, however, that whitebark pine produced 2 to 35 times as many kcal/m²/yr of wildlife forage as these other species and was by far the most important wildlife food source in all stands studied.

EXTENT OF DECLINE

Because whitebark pine has limited value in timber production, data on its status are sparse. Foresters may have difficulty distinguishing between whitebark and limber pine, and many are unfamiliar with the remote high-mountain country where whitebark pine is found. Insect and disease surveys often fail to cover the whitebark pine zone or lump information on whitebark pine with other species. Therefore, available information is sketchy and relies on personal observation. Nevertheless, we believe there is enough evidence to justify concern for the perpetuation of whitebark pine as an important wildlife resource.

Some indirect evidence for a decline in whitebark pine comes from a comparison of past and recent bear studies and observations. R. Daubenmire (1989) encountered squirrel caches of whitebark pine cones that had been excavated by bears in the Selkirk Range of northern Idaho in the 1940's. A 1984 bear study in the Selkirks found no squirrel caches of whitebark pine cones and no whitebark pine seeds in bear scats, although three scats contained a small number of western white pine (*P. monticola*) seeds (Almack 1989). During a black bear study in the southern Whitefish Range of northwestern Montana in the early 1960's, all bears handled in the autumn showed signs of feeding on whitebark pine seeds (Jonkel 1989) (fig. 3). Whitebark pine seeds occurred in 30 percent of fall bear scats collected during that study (Tisch 1961) but in no bear scats observed in this area in the 1980's (Hadden 1989; Jonkel 1989; Kendall, personal observation). In the Mission Range, south of Flathead Lake, MT, most bear droppings observed during fall between 1925 and the late 1930's were entirely composed of whitebark pine seeds (Cheff 1984). Observations of

Figure 3—Black bear captured during a bear ecology study in the southern Whitefish Range, MT, in the early 1960's. The hair on its paws and stomach is matted with pitch from handling whitebark pine branches and cones. All bears trapped in autumn showed similar signs of feeding on whitebark pine seeds, but this has not been seen in the 1980's. (Photo by Charles Jonkel.)

grizzly bears and excavated squirrel middens were common in the whitebark pine zone during this time. No bear feeding activity on whitebark pine has been reported in this area in recent years. More of this sort of comparative information would be helpful.

Mountain Pine Beetle

Some of the only quantitative information on mountain pine beetle mortality in whitebark pine comes from the Northern Region, Forest Service, U.S. Department of Agriculture (headquarters at Missoula, MT). In the Flathead National Forest in this Region, 225,000 acres of whitebark pine suffered some mortality from mountain pine beetle 1975-1988 (Gibson 1988). Most of this occurred in the Whitefish Range, which lost one-half to two-thirds of its whitebark pine in the last 10 years to the combined effects of mountain pine beetles and white pine blister rust (Wilson 1988). Damage to whitebark pine stands ranged from very little mortality to almost 100 percent loss. The mountain pine beetle epidemic in the Whitefish Range originated from a severe infestation in lodgepole pine in adjoining Glacier National Park. Between 1979 and 1985, over 25,000 acres of whitebark pine, primarily in the North Fork of the Flathead River drainage, were infested with mountain pine beetle (Gibson 1988). Much of the whitebark pine in this area was killed, including the oldest whitebark pine trees known in the Park (DeSanto 1989).

Aerial surveys of mountain pine beetle infestations in the Forest Service Intermountain Region (headquarters at Ogden, UT) are for commercial timber only. Thus, substantially more whitebark pine mortality occurs than is indicated in insect damage figures (Knapp 1989). Heavy infestations in the Bridger-Teton and Targhee National Forests are killing large but unknown numbers of whitebark pine. For example, Knapp (1989) estimated that 50 to 75 percent of the whitebark pine on Signal Mountain was killed in recent years. Mountain pine beetle infestations are implicated in whitebark pine cone production decline in the Yellowstone ecosystem between 1980 and 1987 (Knight and others 1988).

The Forest Service Rocky Mountain Region (headquarters at Denver, CO) includes expanses of whitebark pine in the Absaroka and Wind River Ranges of western Wyoming (Steele and others 1983). Little is known about mountain pine beetle damage in those stands except that mortality has been high along the Continental Divide in the Wind River Range (Lister 1989).

In the Forest Service Pacific Northwest Region (headquarters at Portland, OR) whitebark pine is abundant at high elevations along and east of the Cascade Crest in Washington and in the highest mountains of central and eastern Oregon (Arno and Hammerly 1984). It is identified on mountain pine beetle survey maps but is not distinguished from western white pine when damage figures are tallied. It is known that a mountain pine beetle outbreak in northeastern Oregon killed substantial amounts of whitebark pine in the 1970's (Bridgewater 1989).

Dwarf Mistletoe

The few references available on whitebark pine infection by dwarf mistletoe indicate it causes significant mortality in some areas. Cooke (1955) reported "ghost forests" of whitebark pine resulting from dwarf mistletoe on the northwest slopes of Mount Shasta, CA. In the same area, Mathiasen and Hawksworth (1988) found that 96 to 98 percent of the whitebark pine was infected and half had been killed by limber pine dwarf mistletoe. Heavy infections of whitebark pine were also reported in the Copper Mountains, Elko, NV, and near South Pass, Fremont County, WY (Mathiasen and Hawksworth 1988). Whitebark pine has dominated the crater rim community of Wizard Island, Crater Lake National Park, OR, for several centuries. However, recent mortality (45 percent of standing whitebark pine stems less than 4 inches d.b.h. were dead) and little regeneration have diminished the population (Jackson and Faller 1973). Because many living whitebark pine are heavily parasitized by leafless mistletoe, this was suggested as the primary cause of mortality.

White Pine Blister Rust

White pine blister rust is a major source of whitebark pine mortality in areas humid enough to support the spread of spores from one host (*Ribes* spp.) to the other (whitebark pine). Whitebark pine is afflicted by blister rust wherever it is found with infected western white pine. Blister rust has caused heavy losses of whitebark pine from the crest of the northern Cascade Range in Washington to Glacier National Park, MT, and south to Lewiston, ID (Arno, personal observation; Layser 1989). In drier climates, such as the Yellowstone area, whitebark pine is experiencing only minor mortality from blister rust.

Some of the most severe blister rust damage to whitebark pine has occurred in the Forest Service Northern Region, especially in the Cabinet Mountains in northwestern Montana and the Selkirk Range and Bitterroot Mountains (Selway and North Fork of the Clearwater drainages) in northern Idaho (fig. 4) (Arno, personal observation; Hagle 1988). For example, observations and photographs by Arno (1984) indicate that more than 90 percent of the whitebark pine along the Selkirk Crest east of Priest River Experimental Forest was killed by blister rust by the early 1980's. This, no doubt, explains the absence of seeds in bear scats in the Selkirks discussed earlier. A substantial amount of whitebark pine was killed by blister rust in the Whitefish Range, MT, including an area south of Werner Peak in which virtually all the whitebark pine is now dead (Wilson 1988). In the past, this area produced large cone crops that attracted bears. Whitebark pine was a major component of high-elevation forests in portions of Glacier National Park, but blister rust has killed significant numbers, especially on the east side of the park where more than 90 percent has been lost (Buchholtz 1989). Extensive whitebark pine mortality has occurred since the 1930's in the Mission Mountains due to blister rust and mountain pine beetle. Since 1960 there has been continual blister rust mortality of whitebark pine on Desert Mountain south of West Glacier, MT (Schmidt 1989), whereas southward near Observation Peak in the Bob Marshall Wilderness, whitebark pines are just beginning to die from this disease (Keane 1988).

In Washington and Oregon, whitebark pine is damaged by white pine blister rust, but there is no measure of the extent of the problem (Russell 1989). Blister rust has caused significant whitebark pine mortality in the Crater Lake area of Oregon (Harvey 1989). In the Olympic Range, whitebark pine inhabits only the northeastern portion, but some stands, for example, at Constance Pass, have been killed by white pine blister rust (Arno and Hammerly 1984). Whitebark pine is common in northeastern Washington and has died or is dying in many places from blister rust (Layser 1980).

In California, whitebark pine occurs primarily in designated Wildernesses, and there are no quantitative data on distribution or mortality. White pine blister rust had infected whitebark pine in northern California by the 1950's. Increasing amounts of blister rust have been found in the Sierra Nevada in central California in the last 10 years. The rust is beginning to attack sugar pine (*P. lambertiana*) and western white pine at midelevations, so whitebark pine will probably be next (DeNitto 1989). A similar pattern is developing in the Lake Tahoe Basin and on the Lassen National Forest. Western white pine is beginning to contract blister rust, and whitebark pine is expected to follow suit (Kinloch 1989).

IMPLICATIONS FOR MANAGEMENT AND RESEARCH

Widespread loss of whitebark pine has a variety of implications for wildlife management. For example, it may limit efforts to restore grizzly bear populations in areas where, in the past, whitebark pine seeds were an important food. In the Selway-Bitterroot Wilderness, northern Cascade Range, and the Cabinet, Selkirk, and Mission Mountains, grizzly bear and whitebark pine numbers are greatly reduced. With other historically important food sources for bears gone or diminished—for example, depletion of salmon (*Oncorhyncus* spp.) and forage lost to agriculture—whitebark pine cone crops may be a factor in the continued survival or restoration of grizzly bear populations. Yet, this food source (and its decline) is often overlooked in bear habitat evaluations.

Current trends suggest continuing losses of whitebark pine in many areas. Lodgepole pine established after the 1910 fires will be vulnerable to mountain pine beetle attack 10 to 15 years from now (Gibson 1988). Intense infestations are likely to result in high mortality of whitebark pine. Extensive fires and drought create conditions favorable for bark beetle infestations. Mountain pine beetle populations increase in fire-scorched and drought-weakened trees and then spread to adjacent trees.

National Park managers are charged with conserving natural ecosystems including pristine genetic pools. Because white pine blister rust is not native to North America and is causing significant ecological changes, blister rust is of special concern to National Park management. The possibility of an experimental program in

Figure 4—Typical whitebark pine mortality caused by blister rust and possibly mountain pine beetle in the northern portion of the Selway-Bitterroot Wilderness, ID. Scene is on Beaver Ridge, 9 air miles southeast of Lolo Pass. (Photo by S. Arno.)

National Parks to enhance whitebark pine's natural resistance by selecting for resistant genotypes has not yet been considered, but should be.

Our extensive contacts with scientists familiar with whitebark pine communities and the effects of insects and diseases have left little doubt that there is cause for concern about the continuing productivity of this tree. Although a downward trend in whitebark pine abundance is apparent, it is also clear that better information is needed. The first step should be to conduct comprehensive surveys to assess the extent of damage to whitebark pine throughout its range and in various habitat types. Whitebark pine stands should be included in insect and disease surveys.

Additional information on wildlife ecology in whitebark pine communities is also needed. Because of whitebark pine's reliance on Clark's nutcrackers for seed dispersal, it would be useful to know if nutcrackers are no longer attracted to whitebark pine stands with little cone production or at what level of cone production there is not enough seed to cache or virtually all pine nuts are recovered by seed predators.

We must develop management techniques to counteract the problems besetting whitebark pine. We need to find ways to reintroduce fire or mimic its effects in allowing establishment of seral whitebark pine. Techniques for widespread propagation of whitebark pine are needed for a variety of site conditions.

Simulation modeling confirms the observational evidence of decline in whitebark pine in the inland Northwest (Keane and others, this proceedings). Whitebark pine's status as an important mast producer is precarious or already lost in many areas. Wildlife concerns alone make massive cone reductions unacceptable.

Whitebark pine was dominant over a much larger area in the early 1900's than today. A continuation of current successional patterns and mortality trends bodes poorly for whitebark pine. Unless resistant strains can be developed and introduced in large quantities, white pine blister rust will further reduce whitebark pine cone production in moist regions. Whitebark pine often occurs in small geographically isolated populations, which can be destroyed by blister rust or endangered by successional replacement. This, coupled with longer fire intervals, could result in local extinctions and loss of genetic variation. As we seek to mitigate the effects of human activities on wildlife populations, we should make rejuvenation of whitebark pine stands an urgent priority.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from Penny Morgan)—Is a major effort to regenerate whitebark pine justified given the loss of whitebark pine as a resource, especially where we can document loss due to white pine blister rust?

A.—Given the importance of whitebark pine to wildlife, regeneration efforts definitely warrant consideration. Other values include whitebark pine's role in the hydrologic cycle and as a structural component of timberline

communities, as well as its esthetic qualities. There is not currently enough information on many aspects of whitebark pine and white pine blister rust to decide if a major effort is justified. The first step toward answering this question should be to get better information on the status of whitebark pine throughout its range and in a variety of habitat types.

Q. (from Anonymous)—What is the cone crop frequency of whitebark pine? Is it different throughout its range?

A.—Little information is available on annual variation in whitebark pine cone production. According to Bailey (1975), whitebark pine stands tend to cone profusely and simultaneously over large areas at infrequent intervals with very little cone production in the intervening years. However, good cone crops may be produced more frequently in the southern parts of its range. In a Sierra Nevada study area, moderate to heavy whitebark pine cone crops were produced in each of 4 years cone production was rated (Tomback 1978). Data from the greater Yellowstone area suggest that while excellent cone crops are infrequent, moderate as well as poor cone crops are common (Knight and others 1987). Annual cone production was estimated for 29 whitebark pine stands in the northern Rockies (Weaver and Forcella 1986). Excellent cone years were preceded in 20 of 29 cases by average or poorer cone years. Poor cone years were not significantly correlated with yields in any previous year. There is no information on cone crop periodicity in the northwest range of whitebark pine where it is more immediately threatened by disease and successional replacement.

SIMULATING DISTURBANCES AND CONIFER SUCCESSION IN WHITEBARK PINE FORESTS

Robert E. Keane
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ABSTRACT

*Infestations of white pine blister rust (*Cronartium ribicola*) and successional replacement by more shade tolerant conifers can reduce whitebark pine populations. This could adversely affect wildlife species dependent on whitebark pine cone crops including the red squirrel (*Tamiasciurus hudsonicus*), grizzly bear (*Ursus arctos horribilis*), and black bear (*Ursus americana*). The ecological process model FIRESUM (a FIRE SUcession Model) was adapted to whitebark pine (*Pinus albicaulis*) forests and used to simulate effects of long-term successional trends on different seral and climax whitebark pine communities in relation to (1) high severity (crown) fires and fire suppression scenarios, (2) near and far-distant seed sources, and (3) disease epidemics. FIRESUM is a gap-phase model that was used to simulate tree establishment, growth, and mortality on a 400-m² (0.1-acre) plot. Live and dead fuel accumulations, fire behavior and frequency, fuel reduction, and insect- and disease-caused tree mortality were also modeled. Tree establishment and growth in the model are influenced by temperature, water stress, site quality, and light conditions. An additional submodel was included in FIRESUM to simulate the Clark's nutcracker's (*Nucifraga columbiana*) important role in regenerating whitebark pine through seed-caching activities. A test of the FIRESUM model revealed its ability to predict basal areas within 15 percent of those values obtained from inventory data from actual postfire stands.*

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INTRODUCTION

Whitebark pine (*Pinus albicaulis*) is a common tree species of upper subalpine forests and timberlines in the western United States and southwestern Canada. While this species is of limited use for timber, it is highly valued as a food source for wildlife and as cover for snow retention and watershed protection (Arno and Hoff 1989; Day 1967; Forcella and Weaver 1977). Whitebark pine is a component of stands comprising about 10-15 percent of the forested landscape in the Rocky Mountains of Montana, Idaho, and northwestern Wyoming. Most of these whitebark pine stands have not been commercially exploited. However, the species' abundance appears to be threatened by the individual and combined effects of fire suppression, insects, and diseases (Arno 1986). Modeling the effects of these factors on whitebark pine might aid in developing management strategies for maintaining vigorous populations of this species. In addition, modeling will help us understand important ecological relationships in whitebark pine forests.

This paper presents results of an application of process modeling to investigate the effects of fires and diseases on long-term stand dynamics in whitebark pine forests. The computer model FIRESUM (a FIRE SUccession Model) was modified and used for this investigation (Keane and others 1989). The model was used to simulate tree dynamics for four natural and management scenarios using actual field data as inputs. Effects of seed source distance on tree regeneration were also simulated using FIRESUM. Model results were compared with actual field data sampled from two whitebark pine sites.

FIRESUM is a gap-replacement, ecological process model (Shugart and West 1980) following the approach used for JABOWA (Botkin and others 1972) where individual trees are grown deterministically using an annual time step, difference equation. Tree growth and regeneration are affected by several site factors including light, water, tree densities, and temperature. Tree regeneration and mortality are modeled stochastically using Monte Carlo techniques (Keane and others 1989). To simulate whitebark pine regeneration it was essential to modify FIRESUM to account for the role of birds in seed dispersal. Mortality from major insects and diseases was also included in the modeling process.

WHITEBARK PINE ECOLOGY

Whitebark pine is a long-lived, slow-growing tree of high-elevation forests from California and Wyoming north into southern Canada (Arno and Hoff 1989; Day 1967). Throughout most of its range, whitebark pine occurs on two kinds of sites: (1) alpine timberlines and very dry sites where it usually is the climax tree species, and (2) upper subalpine forests where it occurs as a seral species often associated with subalpine fir (*Abies lasiocarpa*), lodgepole pine (*Pinus contorta*), mountain hemlock (*Tsuga mertensiana*), and Engelmann spruce (*Picea engelmannii*) (Arno 1986).

The seeds of whitebark pine are wingless, large (1,180 seeds/kg), and, like most pine seeds, nutritious (Botkin and Shires 1948; Lanner 1982; Mattson 1987; Schopmeyer 1974). These characteristics make the seeds highly desirable to many species of wildlife including the red squirrel (*Tamiasciurus hudsonicus*) (Smith and Follmer 1972), Clark's nutcracker (*Nucifraga columbiana*) (Forcella and Weaver 1977; Tomback 1978), black bear (*Ursus americana*), and grizzly bear (*Ursus arctos horribilis*) (Eggers 1986; Kendall 1980; Mealey 1975). Red squirrels harvest whitebark pine cones and store them in caches or middens on the ground. These middens provide an important, energy-rich food for grizzly and black bears (Mattson 1987; Mattson and Reinhart 1986).

Clark's nutcrackers play a major role in the regeneration of whitebark pine by being the primary means of dispersal for the large, wingless seeds (Hutchins and Lanner 1982; Lanner 1982; Tomback 1982). The nutcrackers harvest seeds from cones on trees and cache these seeds in the surface soil. Seeds not reclaimed by the nutcracker before late spring may germinate and grow into seedlings.

Probably the agents most damaging to whitebark pine are mountain pine beetle (*Dendroctonus ponderosae*), white pine blister rust (*Cronartium ribicola*), wildfire, and successional replacement by more shade-tolerant conifers (Arno and Hoff 1989). Mountain pine beetle killed many mature stands of whitebark pine in the northern Rockies during the years 1909-1940 and again during the 1970's (Arno 1970). Blister rust, an introduced disease, destroys trees in regions where the climate is moist enough to allow it to complete its life cycle. Blister rust is especially damaging to seedlings and saplings (Arno and Hoff 1989), and it also severely damages upper (cone-bearing) branches long before causing mortality in larger trees (Arno 1986). Consequently, epidemics of bark beetles and blister rust in whitebark pine stands jeopardize perpetuation of whitebark pine cone crops in many stands.

The cold, often moist, conditions in whitebark pine forests coupled with sparse fuels result in infrequent fires (50- to 300-year interfire periods) (Arno 1986). Whitebark pine is able to survive low severity fires that kill much of the competing subalpine fir. This creates small openings favorable for regeneration. High severity fires, usually originating from lower elevation forest stands, kill whitebark pines, but the species often becomes more abundant in the postburn community as a result of nutcracker seed dispersal (Arno 1986). Fire suppression favors successional replacement of whitebark pine with subalpine fir on sites where whitebark pine is a seral species.

MODEL DESCRIPTION

FIRESUM is a computer program written in FORTRAN 77 containing 45 subroutines and a main driver program (Keane and others 1989). The model was originally developed from the SILVA model of Kercher and Axelrod (1984) which modeled stand dynamics in ponderosa pine-Douglas-fir forests (Keane and others in press a). Each subroutine in FIRESUM simulates an ecological process and is composed of a specific algorithm driven by a set of associated parameters. Figure 1 presents a modified flow chart showing the names of the important subroutines. FIRESUM models stand dynamics on a 400-m² (0.1-acre) simulation plot. Actual field data from two sites were used to construct the initial simulation stand. Modification of FIRESUM to simulate whitebark pine stand dynamics required the alteration or addition of several algorithms, and the revision of nearly all model parameters. Because routines in FIRESUM are described in detail by Keane and others (1989), only the five most important processes and the new whitebark pine regeneration routines are discussed in this paper.

Growth Process (Subroutine GROW)

Tree growth is modeled by an annual increase in tree diameter at breast height (1.37 m above ground) using annual time-step difference equations. In these equations (table 1), an optimal diameter increase for a tree species (DI) is reduced by four growth reduction factors. The factors (numbers between 0 and 1) model effect of light (rAL), crowding (rN), water stress (rW), and growing season warmth (rC) on tree growth. Process parameters are shown in table 2.

Regeneration Process (Subroutine BIRTH)

Trees are established on the simulation plot if two criteria were met. First, degree-days had to exceed a minimum number of degree days (DMIN) for the species under consideration, and second, the actual to potential evapotranspiration ratio (AET:PET) had to be greater than the minimum value (WSO) for the species (table 2) (Keane and others 1989; Kercher and Axelrod 1984).

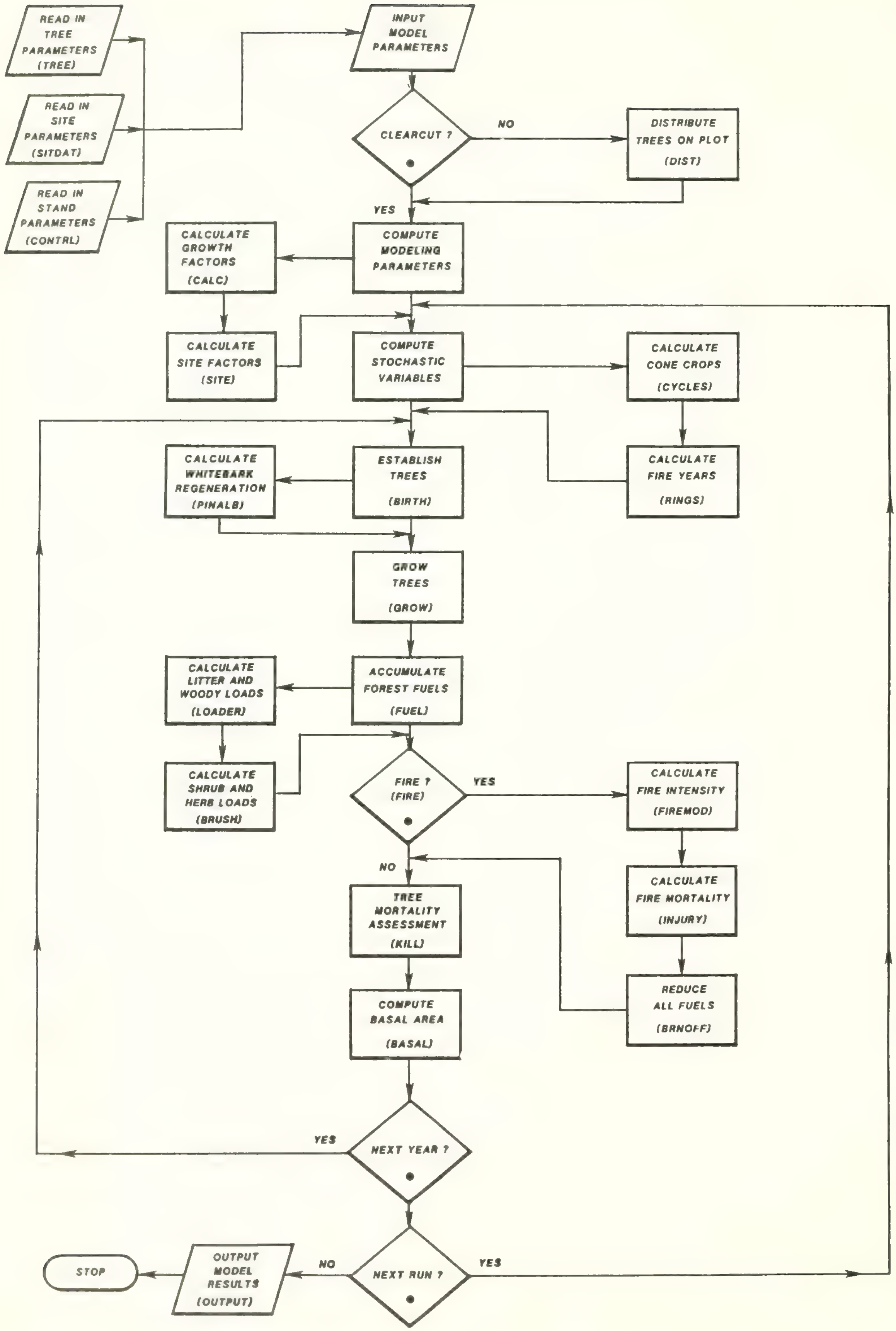


Figure 1—Simplified flow chart for the process model FIRESUM. Names of the FORTRAN subroutines are in parentheses.

Table 1—Descriptions of important equations and algorithms used in the subroutines of FIRESUM

Sub-routine	Important FIRESUM equations	Source or explanation
GROW	$DI = \dfrac{G\,D\,[1-(DH/D_m H_m)]}{274 + 3b_2D - 4b_3D^2}\,\text{rAL rN rW rC}$	Botkin and others (1972)
	DI = annual diameter increment (cm)	
	G = growth parameter calculated in FIRESUM	
	D = tree diameter (cm)	
	$H = 137 + b_2D - b_3D^2$ (cm)	Ker and Smith (1955)
	D_m = max. dia. for a species (cm)	b_2, b_3 derivation shown in
	H_m = max. height for a species (cm)	Botkin and others (1972)
	rAL, rN, rW, rC = growth reduction factors $0.0 < \text{value} < 1.0$	Kercher and Axelrod (1984)
	$AL = AL_0\,e^{-k^*\text{LAI}}$	Kercher and Axelrod (1984)
	AL_0 = available light (full sunlight) standardized to zero	
	k = extinction coefficient (0.426)	Keane and others (1989)
	LAI = sum of leaf area indices for all trees taller than one in question	
	$\text{LA} = \dfrac{[(\text{CW} * \text{PFOL}) / CD] * SV}{\text{PLA}}$	
	CW = crown weight (g)	Brown (1976)
	PFOL = proportion CW that is foliage	Brown (1978)
	CD = needle density (g/cc)	Assumed to be 0.5 g/cc
	SV = needle surface area:volume ratio	Lopushinsky (1970), Brown (1970), Minore (1979)
	PLA = all sided to projected leaf area conversion factor	Kaufmann and others (1982)
	$\text{rAL} = 1 - e^{[-4.64(AL-0.05)]}$ shade tolerant species	Botkin and others (1972)
	$\text{rAL} = 2.24\{1 - e^{[-1.136(AL-0.08)]}\}$ shade intolerant species	Botkin and others (1972)
	rN = 1.0 – (BAR/BARMAX)	BARMAX from Pfister and others (1977)
	BAR = current basal area of plot (square meters)	
	BARMAX = maximum attainable basal area for plot	
	$\text{rW} = 1 - [(1 - \text{APR}) / (1 - \text{WSO})]^2$	Kercher and Axelrod (1984)
	APR = annual AET:PET ratio for simulation site	Used Thorthwaite and Mather (1957) equations
	WSO = lower limit of tolerance in APR	Calculated from actual weather data
	$\text{rC} = \dfrac{[(\text{DEGD} - \text{DMIN})(\text{DMAX} - \text{DEGD})]^V}{[(\text{DOPT} - \text{DMIN})(\text{DMAX} - \text{DOPT})]^V}$	Reed and Clark (1979)
	DEGD = degree-days for simulation site	
	DMIN = minimum degree-days defining a species' range	DMIN, DMAX, DOPT determined from weather data
	DMAX = maximum degree-days defining a species' range	
	DOPT = degree-days needed for optimal species growth	
	V = species-specific constant	Keane and others (1989)

(con.)

Table 1—(Con.)

Subroutine	Important FIRESUM equations	Source or explanation
BIRTH	rSRF = Exp ($a + b\ DS$)	McCaughey and Schmidt (1985)
	rSRF = seed source distance reduction factor	
	a, b = species specific constants	
	DS = distance from seed wall	
	rALs = $e^{(-0.8\ \mathrm{LAI})}$ for shade-intolerants	Based on unpublished data
	rALs = $e^{(-0.25\ \mathrm{LAI}-1.0)}$ for moderate shade tolerants	
	rALs = $1 - e^{(-0.25\ \mathrm{LAI}-0.2)}$ for shade tolerants	
	PSUR = 1.0 – $a\ DD$	Boyce (1985)
	PSUR = proportion of surviving seedlings	
	a = species specific constant	
	DD = duff depth (cm)	
KILL	P_r = 4 / AGEMAX	Botkin and others (1972)
	$P_s = P_s + 0.2 - 0.2\ P_s$	Derived from unpublished data
	$P_f = \dfrac{1}{1+\mathrm{EXP}[-1.941+6.32(1-\mathrm{EXP}(BT))+0.000535C^2]}$	Ryan and Reinhardt (1988)
	P_r = random or background mortality	
	P_s = stress mortality	
	P_f = fire mortality	
	BD = bark thickness (cm)	
	C = percent of crown scorched (%)	
	AGEMAX = maximum attainable age (yr)	

Table 2—Parameter values for whitebark pine forest species implemented in FIRESUM[1]

Parameter	Tree species[2]				
symbol (units)	PIAL	PICO	LALY	ABLA	PIEN
H_m (cm)	3,657.000	4,115.000	3,048.000	4,175.000	5,456.000
D_m (cm)	182.000	110.000	168.000	126.000	234.000
AGEMAX (years)	1,000.000	350.000	800.000	250.000	300.000
DMIN (deg-days)	800.000	1,500.000	800.000	1,003.000	1,003.000
DOPT (deg-days)	3,000.000	3,000.000	3,000.000	3,800.000	3,800.000
DMAX (deg-days)	5,200.000	6,500.000	5,200.000	6,200.000	6,200.000
Shade tolerance	M	I	I	T	M
SV (cm^2/cm^2)	57.600	64.700	184.000	70.000	54.200
PLA (m/m)	3.540	3.540	3.540	2.040	2.040
WSO (proportion)	.330	.400	.750	.650	.650
Pc (probability)	N/A	.318	.368	.333	.167
hc (years)	1.000	2.000	1.000	2.000	3.000
BC (proportion)	.015	.014	.031	.015	.022
DKF (proportion)	.057	.044	.201	.034	.034
DKL (proportion)	.112	.112	.200	.067	.067
LTD (proportion)	.550	.660	.650	.650	.650
DKD (proportion)	.221	.221	.321	.221	.221
AINC (cm)	.006	.016	.007	.008	.008
Lc (percent)	50.000	40.000	45.000	80.000	80.000
NYR (years)	7.000	3.000	1.000	7.000	6.000

[1]Sources for model parameters are listed in Keane and others (1989). Variables not defined in text or table 1 are shown in Keane and others (1989).
[2]PIAL-whitebark pine, PICO-lodgepole pine, LALY-alpine larch, ABLA-subalpine fir, PIEN-Engelmann spruce.

If these criteria were met, the size of the cone crop was then evaluated. The procedure described below is used for every species in the model except whitebark pine. Since whitebark pine seed is dispersed by the Clark's nutcracker, its regeneration algorithm is presented in detail later in this paper.

Each year a species (not including whitebark pine) can have a good or poor cone crop, and trees are established only in the year following good cone crop years. Cone crop years are computed stochastically using Monte Carlo techniques discussed in Kercher and Axelrod (1984).

The actual number of trees established on the simulation plot (FNJ) for a species is calculated from the equation:

$$FNJ = SPM * PTREE * PSUR * rSRF * rALs \qquad (1)$$

where SPM is the maximum number of seedlings that can become established on a square meter (10.8 ft^2), 0.87 was used for this investigation (Keane and others, unpublished data); PTREE is number of seed trees for the species under consideration divided by the total number of seed trees for all species (Keane and others 1989); and PSUR is a reduction factor (table 1) simulating the proportion of seedling survival as a function of duff depth (Boyce 1985; Keane and others 1989). The reduction factor rSRF models the effect of distance to seed source on seedling establishment (table 1). Equations used to compute rSRF for each tree species are a modification of the dispersal curves of McCaughey and others (1986) (fig. 2). Lastly, rALs is a reduction factor simulating seedling survival under various light conditions as a function of leaf area and shade tolerance (Keane and others 1989). All new trees, including whitebark pine trees, are established as saplings of 1.0 cm diameter at breast height (d.b.h.) and 1.37 m tall. These new trees are included after a lag period of 25-50 years depending on the site.

Whitebark pine regeneration is computed in subroutine PINALB, which models the effects of seed crop, nutcrackers, and light on whitebark regeneration. Four cone crop classes are used in PINALB: none, poor, moderate, and good, with each class having an associated probability of occurrence (p_w) and a crop reduction factor (rCONFAC)

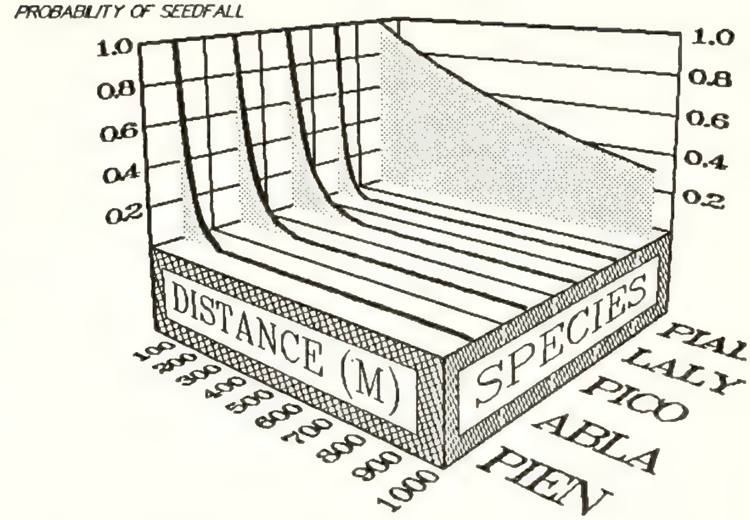


Figure 2—Seed dispersal curves for several tree species. Probability of seedfall describes the chances a seed will fall to the ground at various distances. Whitebark pine (PIAL) curve from Tomback and others (1989); all other curves were derived from McCaughey and others (1986). Symbol definitions include ABLA: subalpine fir, and PIAL: whitebark pine, LALY, subalpine larch, PIEN: Engelmann spruce, and PICO: lodgepole pine.

(table 3). Cone crop class is determined stochastically using random number generation. The number of cones on a whitebark pine tree (CPT) is computed using the equation:

$$CPT = CMAX * rCONFAC * rCRF \qquad (2)$$

where CMAX is the maximum number of cones per tree (table 3) and rCRF is another crop reduction factor that is a function of tree age (fig. 3a). The total number of cones produced on the simulation plot (CONES) is calculated by

Table 3—Parameters used in the whitebark pine regeneration algorithm and associated references

Symbol	Description and reference	Class	Value
p_w	Probability of cone crop class	Good	0.2175
	Mattson (1986),	Moderate	0.3152
	Weaver and Forcella (1986)	Poor	0.3152
		None	0.1521
CMAX	Maximum number of cones/tree		80.0000
	Arno and Hoff (1989),		
	Mattes (1984)		
rCONFAC	Reduction factor for cone crop class	Good	– 1.0000
		Moderate	– 0.6700
		Poor	– 0.3300
		None	– 0.0000

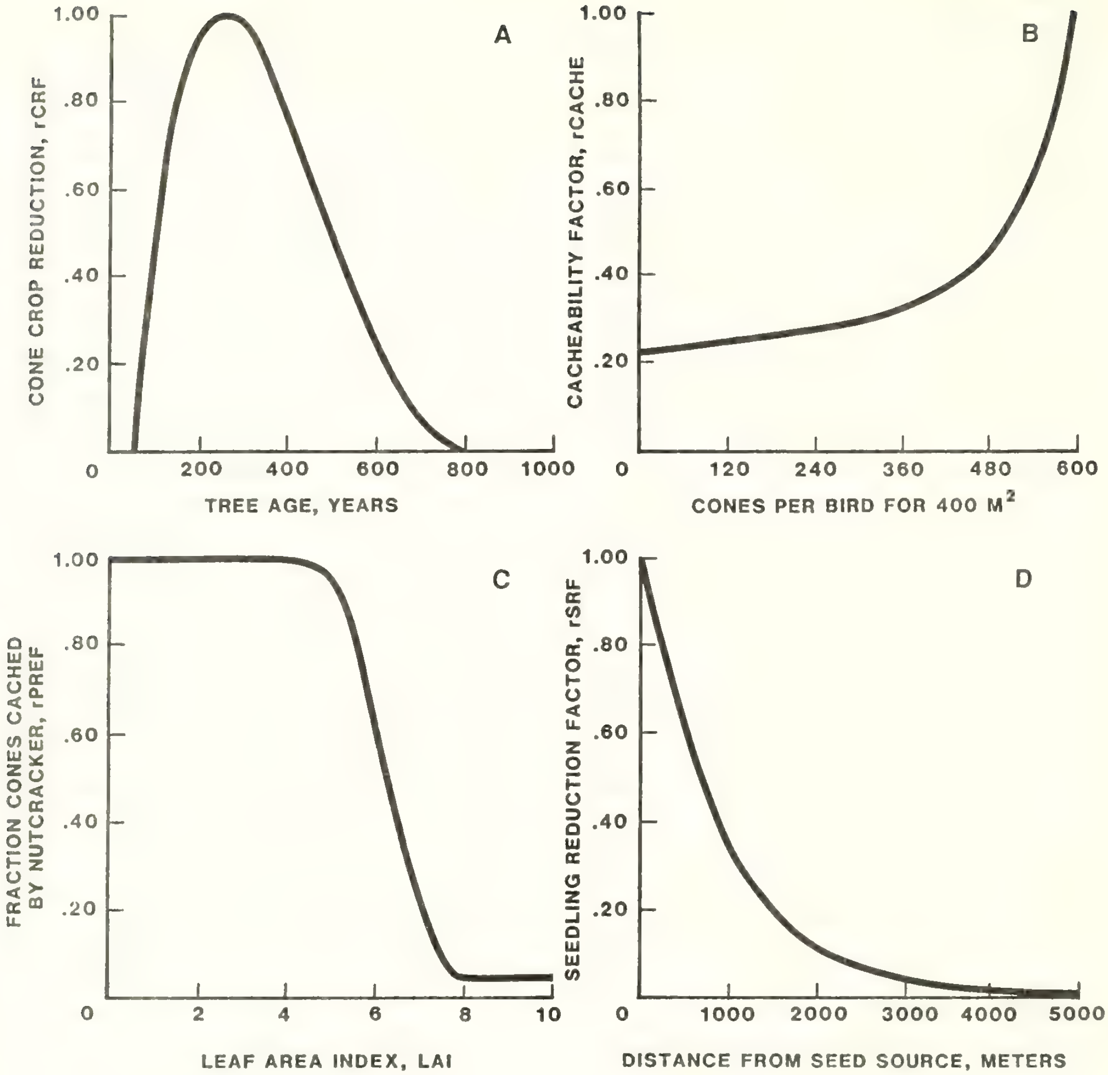


Figure 3—Reduction factors used for modeling whitebark pine regeneration with respect to whitebark pine seed dispersal by nutcrackers. Factor rCRF is the cone reduction factor (A), rCACHE is the caching frequency reduction factor (B), rPREF is the site preference reduction factor (C), and rSRF is the seedling reduction factor for distance from seed source (D).

summing the cones per tree across all cone-bearing trees on the plot. A cone-bearing tree is a tree at least 60 years of age or 20 cm d.b.h. (Arno and Hoff 1989). The total number of whitebark pine seeds (NSEED) is computed by multiplying CONES by the number of seeds per cone (SPC), taken to be 68.8 for this study (Weaver and Forcella 1986).

It is assumed all whitebark pine seeds are dispersed by the Clark's nutcracker (Hutchins and Lanner 1982; Tomback 1982) and the number of seeds imported to the site is equal to the number exported. Because the seed import:export ratio may vary across sites, it is assumed site conditions for the simulation plot are similar to surrounding areas. Although a cluster of seedlings can emerge from a nutcracker cache, we considered the mature tree, single or clustered form, to function as a single tree (Linhart and Tomback 1985). The total number of seedlings (TNS) established on the plot is computed from:

$$TNS = \left[\frac{NSEED * (1 - PFIND) * (1 - PCONS)}{SPCAC}\right] * (rCACHE * rPREF * rSRF * rALs) \qquad (3)$$

where PFIND is the proportion of seeds reclaimed by the nutcracker during the following winter and spring (assumed as 0.8) (Tomback 1982), PCONS is the proportion of seeds eaten by the nutcracker during caching season (calculated as 0.11 from Tomback 1982), and SPCAC is the average number of seeds per cache (=3.7) (Tomback 1978). The last four terms in the equation are regeneration reduction factors (numbers between 0 and 1).

The reduction factors in the equation above account for the more important factors influencing dispersal and survival of whitebark pine seedlings. Frequency of nutcracker visitation is modeled using rCACHE or cacheability. This function (fig. 3b) is dependent on the number of cones per bird (CPB) calculated by dividing the total cones (CONES) by the number of nutcrackers which is an input to FIRESUM. Factor rPREF models the appeal of the site to nutcrackers and uses leaf area index as the driving variable (fig. 3c). The more shaded a site becomes (high LAI) the less appealing the site is for nutcracker caching (extrapolated from Tomback 1978, 1982). The relationship of distance to seed source and caching intensity is modeled using rSRF. This function (fig. 3d) shows seeds may be carried up to 5,000 m from a seed source (Tomback and others 1989). Lastly, rALs simulates the effect of light conditions on seedling survival as previously presented for all other tree species. Because Clark's nutcrackers consistently cache whitebark pine seed 1-3 cm below duff surface (Tomback 1982), duff depth was assumed to be an unimportant factor affecting whitebark pine regeneration.

The absence of seed trees for a species on the plot presents a special case in FIRESUM. Distances to seed source from simulation plot by species are input into the model. The factor rSRF and the number of seed trees are computed annually for each species. However, the value of rSRF only enters into the seedling equation(s) when all seed trees of that species are eliminated from the simulation plot, because of beetle epidemic or successional replacement, for example. It is assumed in FIRESUM that the seed source of eliminated species composes 5 percent of the total seed crop trees outside the simulation plot (Keane and others, in press a) for all tree species but whitebark. In the absence of whitebark pine seed trees, the number of seeds carried to the site is 10 percent of CMAX times SPC. If all trees are killed on the plot, such as after a crown fire, the composition of the seed source stand is assumed to be identical to the preburn simulation stand.

Mortality Process (Subroutine KILL)

Trees die in FIRESUM from four types of mortality that are modeled as an annual probability of death. The first type is called random or background mortality. This probablity (P_r in table 1) is the chance of death from endemic disturbances, such as windthrow, a tree experiences each year of its life (Keane and others 1989). The second type, stress mortality, results from severe stress over long periods because of limited light, water, or crowding conditions. The probability of stress death (P_s in table 1) is a function of diameter growth increment and is only considered when a tree's annual growth increment becomes less than a threshold value (AINC in table 2). The third type of tree mortality is from fire. When a fire occurs on the simulation plot it kills trees by scorching foliage and killing cambium. Ryan and Reinhardt (1988) developed FIRESUM's empirical fire mortality equation, which uses percentage crown scorched (Van Wagner 1972) and bark thickness as independent variables (P_f in table 1). This equation is used for all tree species.

Insect and disease epidemics account for the last type of mortality. Currently, FIRESUM simulates only mountain pine beetle and white pine blister rust infestations. The year in which the beetle or rust infestation starts is input by the user. Tree mortality after the start of an epidemic is modeled as an annual probability of death. Since the objective of this study was to model the effects of blister rust infestations, the mountain pine beetle algorithm will not be discussed.

Once a blister rust epidemic begins, each whitebark pine has a probability of infection assumed as 0.60 (Keane and others, unpublished data). If a tree becomes infected, the probability of death from blister rust (P_i) is computed annually using the equation:

$$P_i = e^{-0.15 * \mathrm{DBH}} \qquad (4)$$

where DBH is the tree diameter (cm). A tree remains infected all its life and, once infected, its cone crop is reduced by 90 percent. Whitebark pine's resistance to blister rust is modeled as a probability of resistance (= 0.05 based on consultation with Ray Hoff [Hoff 1987]). Each established tree is determined to be either resistant or nonresistant based on Monte Carlo techniques using the probability of resistance. Blister rust kills only whitebark pine for all simulations.

Fuel and Fire Processes (Subroutines FUEL and FIRE)

Six dead and two live fuel components are modeled in FIRESUM: four dead downed woody (litter, 1 -, 10 -, and 100-hour timelag), dead shrubby, dead herbaceous, live shrub, and live herbaceous. Loadings for these components are computed annually and used to determine fire intensity (Keane and others 1989). Litter and duff loadings are dynamically modeled in FUEL using compartments (Keane and others 1989; Kercher and Axelrod 1984).

Fires are simulated in FIRESUM by computing fire intensity, flame length, and scorch height from fuel loadings and weather conditions using the FIREMOD subroutine developed by Albini (1976). FIREMOD uses Rothermel's (1972) model to compute the fire behavior characteristics. Fire occurrence is input by the user for a specific year, selected intervals, or stochastic intervals. After a fire occurs, duff, litter, and woody fuel loadings are reduced in subroutine BRNOFF using regression equations from Brown and others (1985). Fire weather conditions and fuel moistures are also inputs to the model. The values used in this study were taken from data measured for a hot day in August after a 2-week dry period. These are the conditions under which most fires occur in whitebark pine forests.

Table 4—Site descriptions of the two stands used in the testing and evaluation of FIRESUM

Site location	Elevation	Aspect class	Slope	Disturbed age	Rust infest.	Beetle kill
	Meters		*Percent*	*Year*		
One Horse Ridge (PIAL h.t.)	2,634	Southwest	21	96	Little	Yes
One Horse Ridge (ABLA h.t.)	2,329	Northeast	70	99	Little	No

METHODS

Field Data Collection

Site, vegetation, and climate data were collected at two whitebark pine sites on One Horse Ridge in the Bitterroot Mountains southwest of Missoula, MT (table 4). The ridgetop site is a whitebark pine habitat type (PIAL h.t.) in which whitebark pine is the indicated climax species as described by Pfister and others (1977). This site has a southern aspect and is substantially drier than the north-slope site, which is a subalpine fir habitat type (ABLA h.t.) in which whitebark pine is a major seral tree species. The ABLA h.t. site represents intermediate moisture conditions for a whitebark pine site.

Field data were obtained by sampling methodologies discussed in detail in Keane and others (in press a, b). In summary, at each site, vegetation and environmental data were gathered for both a mature stand and an adjacent young stand that had arisen after a stand-replacement wildfire in the late 1800's (young stands were 99 years old). Sample plots were 400 m^2 and located in representative portions of the stands. The following variables were measured for each stand: stand age, tree density and diameters, aspect, slope, elevation, and fuel loadings. Weather data for these sites were extrapolated from historical weather data from similar whitebark pine sites (Arno 1970) and modified using the climate model MTCLIM (Hungerford and others 1989).

Simulation Framework

The model FIRESUM was used to investigate the effects of fire and blister rust on seral and climax whitebark pine sites using nearby and distant seed sources. First FIRESUM was calibrated using data collected by Keane and others (in press b) in climax and seral whitebark pine stands. Then sample data from the mature stands on both One Horse Ridge sites were used as inputs to the model to create initial simulation stands. Sampled site and climate data were also model inputs. Then, the following natural and management scenarios were simulated for both sites:

1. No fires—complete fire suppression.
2. Crown fire at year 150—a stand-removing wildfire is initiated at simulation year 150.
3. Blister rust infection at year 150—a blister rust epidemic is initiated at simulation year 150 with no fires throughout the simulation period.
4. Blister rust infection at year 100, crown fire at year 150.

The crown fire scenario was conducted for two conditions: nearby and distant seeds sources. The distant seed sources were input as 3,000 m from the simulation plot. This attempts to replicate the differences between small and large burns. Results of each scenario and seed source distance effects were compared.

Model Verification

The mature stand data from the two sample sites were used as inputs to FIRESUM. Subsequent predictions at simulation year 99 were then compared with data collected in the young stands (age 99) at each site (Keane and others, in press a). The variables compared were basal area by tree species and fuel loadings.

RESULTS AND DISCUSSION

Simulations compare consequences of four natural and management scenarios for the One Horse Ridge PIAL h.t. and ABLA h.t. sites (figs. 4 and 5, respectively). These results show successional trends for a close or nearby seed source (small burn) for all tree species. Simulation results for distant seed sources (large burn) after crown fires on the two sites are also presented (fig. 6). A detailed technical discussion of FIRESUM performance is provided by Keane and others (1989).

Model Results

Fires simulated in FIRESUM were crown fires that killed and consumed all trees on the simulation plot. Actual or "real world" fires moving through these plots would often be of low to moderate intensity (flame lengths of 0.5-1.5 m or 1-3 ft, 1- to 4-m scorch heights) because of the sparse fuel loadings. Simulated surface fires ranged from 250 to 300 kW/m fireline (1.9- to 3.88-m scorch heights) on the ABLA h.t. site and 180 to 250 kW/m fireline (1.1- to 2.3-m scorch heights) on the PIAL h.t. site. These fires were not capable of igniting the crown and destroying all trees on the simulation plot. Therefore, it was assumed the crown fire did not originate on the simulation plot but was carried there from other stands.

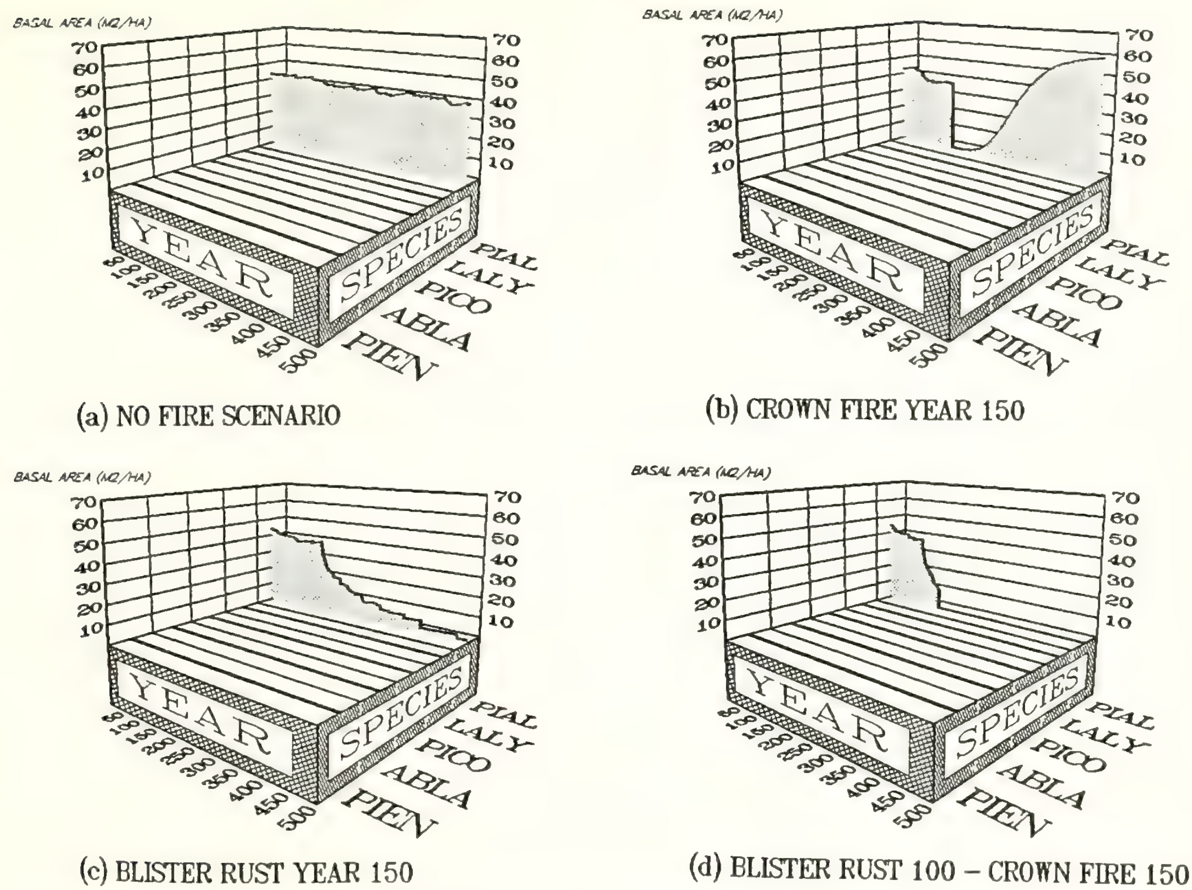
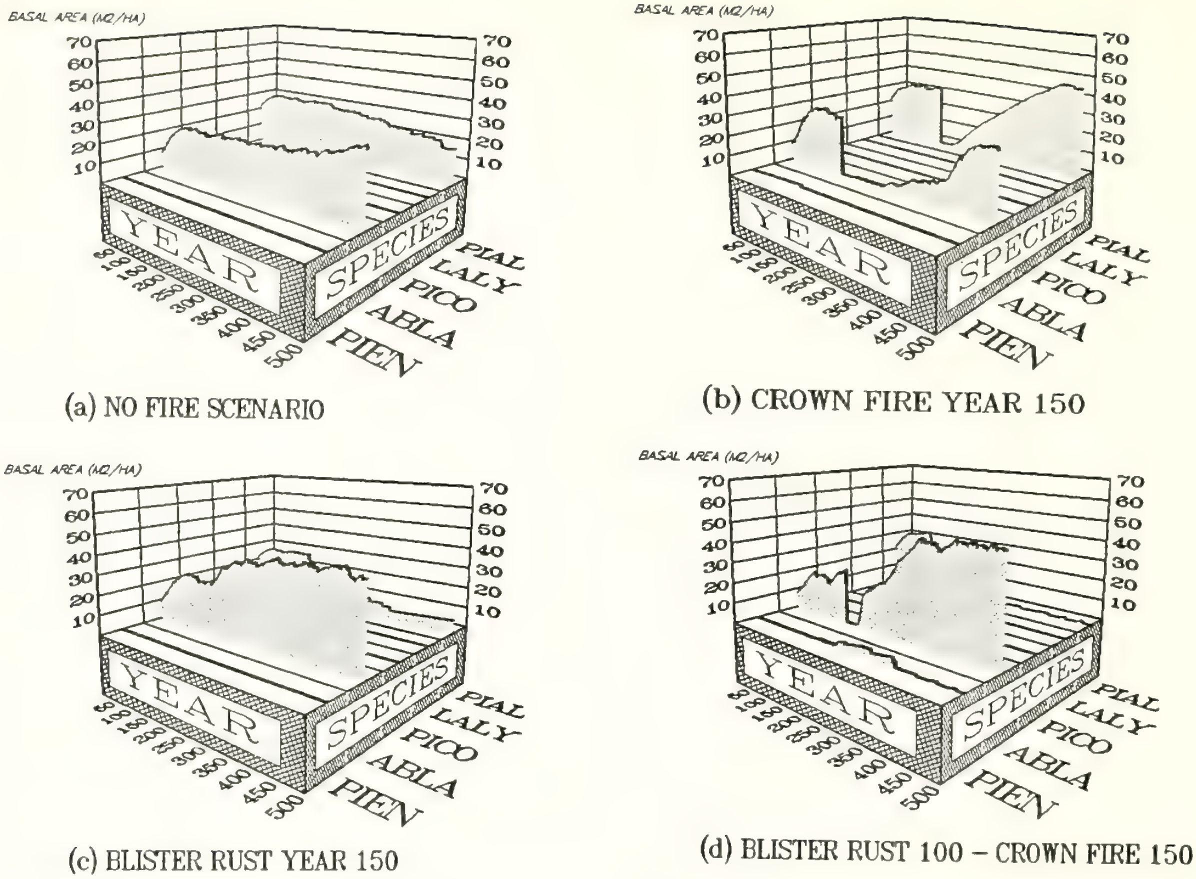


Figure 4—Basal area predictions for tree species on the One Horse Ridge PIAL h.t. Four scenarios are shown: (a) no fires (fire suppression), (b) crown fire at year 150, (c) blister rust epidemic at year 150, (d) blister rust at year 100 and crown fire at year 150. Symbol definitions include ABLA: subalpine fir, and PIAL: whitebark pine, LALY, subalpine larch, PIEN: Engelmann spruce, and PICO: lodgepole pine.

Simulated woody fuel loadings were much greater on the ABLA h.t. site (0.29 to 0.39 kg/m^2) compared with those on the PIAL h.t. site (0.19 to 0.23 kg/m^2). Predicted duff depths and fuel loadings varied greatly by scenario. Simulated leaf areas averaged around 1.5 to 2.6 m^2/m^2 for the PIAL h.t. site and 3.0 to 6.9 m^2/m^2 for the ABLA h.t. site.

No Fire Scenario—Results from the fire suppression scenario differ between the two whitebark pine sites (figs. 4a and 5a). With the exclusion of fire, whitebark pine (PIAL) remains the dominant species on the PIAL h.t. site. On the ABLA h.t. site, PIAL is replaced successionally by the more shade-tolerant subalpine fir (ABLA). There is also a corresponding decline in whitebark pine cone production on the ABLA h.t. site (table 5). Maximum fuel loadings for these stands tended to be similar (0.216 kg/m^2 for PIAL h.t. and 0.362 kg/m^2 for ABLA h.t.) indicating a potential for high severity wildfires after many decades of fire suppression. In the model simulation, the moist ABLA h.t. site was able to support small quantities of Engelmann spruce (PIEN) and lodgepole pine (PICO), although this is not evident in the graph (fig. 5b) because of the small basal area values. The composition and basal area of PIAL for the PIAL h.t. site (fig. 4a) correspond with those observed by Pfister and others (1977) for the whitebark pine (PIAL) habitat type. Average duff depth was much greater for the ABLA h.t. site (3.2 to 5.4 cm) when compared with the PIAL h.t. site (0.8 to 2.2). This is mainly due to the smaller leaf areas on the PIAL h.t. site indicating a smaller amount of needlefall.

Crown Fire Scenario—Successional trends after crown fires are somewhat similar between sites (figs. 4b and 5b). On the PIAL h.t. site, whitebark pine became well established within 25-40 years after fire and this species reached preburn basal areas after 150 years of simulation. On the ABLA h.t. site, whitebark pine became established after 25-35 years but attained prefire basal area much quicker (70-80 years). The shade tolerant ABLA was eliminated from the ABLA h.t. site by crown fire and did not become a significant component in the stand until a century after the fire (fig. 5b). On the ABLA h.t. site, even though a crown fire occurred at year 150, the average number of cones per year for all 500



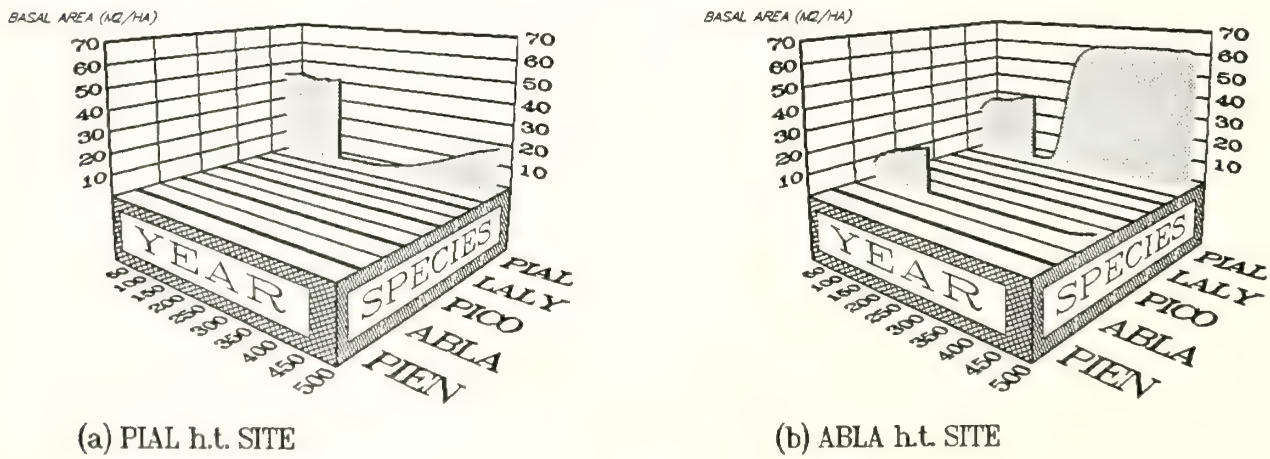
(a) NO FIRE SCENARIO

(b) CROWN FIRE YEAR 150

(c) BLISTER RUST YEAR 150

(d) BLISTER RUST 100 – CROWN FIRE 150

Figure 5—Basal area predictions for tree species on the One Horse Ridge ABLA h.t. site where whitebark pine is the major seral tree species. Four scenarios are shown: (a) no fires (fire suppression), (b) crown fire at year 150, (c) blister rust epidemic at year 150, (d) blister rust at year 100 and crown fire at year 150. Symbol definitions include ABLA: subalpine fir, and PIAL: whitebark pine, LALY, subalpine larch, PIEN: Engelmann spruce, and PICO: lodgepole pine.



(a) PIAL h.t. SITE

(b) ABLA h.t. SITE

Figure 6—Basal area predictions for tree species on the One Horse Ridge PIAL h.t. and ABLA h.t. sites when the seed source after fire is 3,000 m from the simulation plot. Two scenarios are shown: (a) PIAL h.t. site-crown fire year 150, (b) ABLA h.t. site-crown fire year 150. Symbol definitions include ABLA: subalpine fir, and PIAL: whitebark pine, LALY, subalpine larch, PIEN: Engelmann spruce, and PICO: lodgepole pine.

Table 5—Average number of whitebark pine cones produced each year on the simulation plot for the 500-year simulation period

Scenario	Average cones/year	
	PIAL h.t. site	ABLA h.t. site
1 - No fires (fire suppression)	166	102
2 - Crown fire year 150	134	219
3 - Blister rust year 150	109	55
4 - Blister rust year 100-Crown fire year 150	44	42

years of this scenario was greater than all years in the no fire scenario (table 5).

Duff depths (1.9 to 3.5 cm) and fuel loadings (0.201 to 3.120 kg/m²) for the ABLA h.t. site were much less than those predicted for the no fire scenario. This is a result of the decrease in ABLA and the corresponding increase in PIAL. PIAL tends to cast less foliage and dead branches than ABLA, probably because of its smaller leaf area. The decrease in leaf area (2.2 to 4.3 m²/m²) was also evident in the simulation results for the ABLA h.t. site when compared to the no fire scenario.

Blister Rust Scenario—Blister rust infections resulted in severe reductions of whitebark pine over long periods (greater than 500 years) for both sites (figs. 4c and 5c). Whitebark pine decreased throughout the simulation and is expected to be absent from the PIAL h.t. site by simulation year 750 (fig. 4c). The long, gradual decline of whitebark pine is the consequence of the great longevity of the species. On the ABLA h.t. site, subalpine fir replaced whitebark pine as the dominant tree species (fig. 5c). On both sites, the whitebark pine cone crop declined markedly as a result of the blister rust (table 5).

Duff depths and fuel loadings decreased on the PIAL h.t. site (0.5 to 0.9 cm and 0.14 to 2.1 kg/m²) and increased on the ABLA h.t. site (4.7 to 5.9 cm and 0.29 to 0.40 kg/m²) when this scenario is compared with the no fire and crown fire scenarios. This is because of the decline of PIAL on PIAL h.t. site and increase in ABLA on the ABLA h.t. site.

Blister Rust-Crown Fire Scenario—This scenario illustrates the probable effects of crown fires in the blister-rust-infected whitebark pine stands common in Washington, northern Idaho, and northwestern Montana. Whitebark pine trees are unable to regenerate on the PIAL h.t. site due to the blister rust (fig. 4d). Consequently, trees never become established on the site and it is converted to high-elevation grassland or alpine tundra. Blister rust also prevented whitebark pine regeneration on the ABLA h.t. site (fig. 5d), but subalpine fir (ABLA) was able to regenerate, grow, and become the dominant tree species.

Distance to Seed Sources—The distance from seed source to simulation plot dictates the composition of whitebark pine sites (fig. 6). Comparing nearby (fig. 4b) and distant (fig. 6a) seed sources for the PIAL h.t. site reveals that the recovery time after fire is much greater when the seed source is distant. Whitebark pine on the ABLA h.t. site (fig. 6b) is the only species able to become established and grow when the seed sources are 3 km away. This is a result of the great distance Clark's nutcrackers will fly to cache whitebark pine seed (see fig. 2). Only nearby seed sources (fig. 5b) provide for the prompt establishment of subalpine fir.

Verification Results

Test results show FIRESUM predictions seem to be comparable to conditions measured at the disturbance stands (table 6) after 99 years of simulation. Predicted whitebark pine basal area for the PIAL h.t. and ABLA h.t. sites is within 10 percent and 27 percent of the

Table 6—Verification results of the model FIRESUM for two whitebark pine sites[1]

Variable	PIAL h.t.		ABLA h.t.	
	Observed	Predicted	Observed	Predicted
Whitebark pine basal area	16.80	15.10	7.40	10.20
Subalpine fir basal area	0.10	0.00	0.40	1.20
1-hour time-lag fuel loading	0.08	0.06	0.06	0.11
10-hour time-lag fuel loading	0.08	0.06	0.06	0.11
100-hour time-lag fuel loading	0.30	0.25	0.21	0.93
Duff depth	1.75	1.43	1.10	1.50

[1]Units for basal area values are in meters squared per hectare, fuel loadings are in kilograms per meter squared, and duff depths are centimeters.

observed values, respectively (table 6). However, the observed and predicted fuel loadings differ; this could be a result of inaccurate decomposition parameters and calibration data. FIRESUM seems to overpredict basal areas for all tree species. This is probably because of the inadequacy of FIRESUM to model the harshness of the microenvironment for tree establishment and growth in these high-elevation stands.

CONCLUSIONS

FIRESUM modeling results indicate that the combined effects of fire suppression and blister rust infections could severely reduce whitebark pine populations (figs. 4 and 5) and their cone crops (table 5). This may affect population levels of red squirrels, Clark's nutcrackers, bears, and perhaps other animals inhabiting or utilizing high-elevation forests. White pine blister rust reduces and may eventually eliminate whitebark pine cone crops as a significant food source in some areas (table 5 and figs. 4c and 5c).

The ability of whitebark pine to colonize large burns is much greater than that of subalpine fir due to seed dispersal by nutcrackers (fig. 6).

Possible methods of increasing whitebark pine populations and cone crop levels may be inferred from these simulation results. Allowing crown fires to occur on sites where whitebark pine is a seral species may increase whitebark pine populations. In areas where blister rust mortality is prevalent, planting rust-resistant whitebark pine might help perpetuate this species in sufficient amounts to provide a continued food source for wildlife.

These FIRESUM results are only a first approximation of modeling for whitebark pine forests. Although forecasts seem to agree with data collected from field studies (Arno 1986; Pfister and others 1977), we plan to continue testing the model against actual stands and refine our characterizations of whitebark pine forest succession. Many parameters and equations in FIRESUM have not yet been accurately quantified for high-elevation ecosystems. In addition, we wish to identify and characterize any important ecological processes in the high-elevation forests that are not presently simulated in FIRESUM, such as the quality and quantity of sunlight.

ACKNOWLEDGMENTS

We would like to thank the following who helped develop the whitebark pine version of FIRESUM: Ken Gibson and Sue Hagle of the Northern Region, Forest Service, and Ward McCaughey, Wyman Schmidt, Raymond Hoff, Sally Hejl, and Gene Amman of the Intermountain Research Station, Forest Service; Penny Morgan and Steve Bunting, University of Idaho, Moscow; Hans Zuuring and Brian Steele, University of Montana, Missoula.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from Jerry Covault)—Your model says a stand-replacement fire (one less than 3,000 m from seed source) would have PIAL come back. Katherine Kendall pointed out that this situation in the Great Burn did not result in the reestablishment of PIAL. Is the model wrong?

A.—No. The Great Burn was an extremely intense fire burning many acres of forest and leaving large continuous landscapes devoid of trees. History tells us that during the period after the burn, many sheep were brought to the area by rail and were grazed extensively throughout the burn. The sheep could have prevented or delayed whitebark pine establishment. The blister rust may have also had an effect on the species establishment. If we knew all factors involved I think we could model the results of the Great Burn fire and get relatively accurate results.

Q. (from Dave Mattson)—Where did you get cone production figures for PIAL and ABLA habitat types?

A.—Cone production figures were computed from data that you collected from your sample stands in the Yellowstone area. Checks of your figures were taken from work by Weaver and Forcella (1986) and Arno and Hoff (1989).

Q. (from Don Despain)—Does your model account for seeds already on the site, those that don't need to disperse in?

A.—Yes. The model puts seed on the simulation plot before the first simulation year.

Q. (from Dick Baker)—For your high elevation (PIAL h.t.) in the blister rust-crown fire scenario I was surprised to see that the site converted to a grassland. What happened to the nutcracker dispersal capability for 350 yrs?

A.—Nutcrackers still cached seeds on the simulation plot, but due to adverse site conditions and the blister rust, the seedlings were unable to grow to maturity.

Q. (from Ray Hoff)—What happens when you add some resistance to blister rust for whitebark pine in your model?

A.—I did model 5 percent resistance in the whitebark pine (each tree established had a 5 percent chance of being resistant to the blister rust) and found that the severity of the site and nutcracker dispersal did not allow any of the resistant trees to grow to maturity.

Q. (from Anonymous)—Why didn't you model mountain pine beetle in your model?

A.—We did, but presented the results in another paper that was submitted for publication in the journal "Ecological Modelling." The paper was titled: "Modeling Stand Dynamics in Whitebark Pine Forests".

SESSION 4

Management Implications

Wendel Hann and Kathy Hansen-Bristow
Session Coordinators

Papers in this section examine the ecological background of the various resources of high-mountain ecosystems and their implications for management. Included are wildlife, livestock, fisheries, hydrology, recreation, and timber resources and how these interact with changes in biological diversity, fire behavior, and silvicultural practices. There is little experience in active management of whitebark pine ecosystems, so the management implications presented here are essentially charting new ground.

WILDLIFE RESOURCES AND HABITAT MANAGEMENT OBJECTIVES IN THE WHITEBARK PINE ECOSYSTEM

Dan Tyers

ABSTRACT

Several principles become apparent in managing for the wildlife resource in the whitebark pine (Pinus albicaulis) *ecosystem. First, much of the value placed upon this ecosystem is transferred to it because of its value to the grizzly bear—a high-profile species due to its listed status. Second, if management of the wildlife resource in the whitebark pine ecosystem is to be successful it must be integrated and carefully coordinated with other legitimate resources such as timber, recreation, and range. Third, for wildlife, this ecosystem cannot be managed as an island. It must be managed with sensitivity to the total habitat requirements of wildlife that use it.*

Grizzly bear, bighorn sheep, and moose management options are discussed as examples of programs that apply to these three principles.

It falls to wildlife biologists to develop management programs that express the importance of this ecosystem. In general, our understanding of the actual habitat requirements of wildlife as they relate to the whitebark ecosystem is often no more specific than an awareness that the area deserves special management consideration. Attempting to clarify and quantify the habitat requirements of each wildlife species in the whitebark ecosystem is a continuing effort. The level that we generally operate at usually results in setting the objective of simply preserving the integrity of the area.

INTRODUCTION

It seems to be generally recognized that our understanding of the habitat requirements of wildlife in the subalpine and timberline forests of the West is less well developed than it is for lower elevation forests (Arno and Hoff 1989; Raphael 1987; Thomas 1987). This would include forests where whitebark pine (*Pinus albicaulis*) is found. It has been suggested that this paucity of information is the result of a comparative lack of accessible and available resources in this ecosystem. Available resources generate management and research attention, which generates information. As resources become more finite and the demand for them expands even into the comparatively remote whitebark pine ecosystem, interest in these areas is being generated. Wildlife managers and biologists are left playing a catchup game to keep pace with the demand for information this interest has created.

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Studies have shown that subalpine and timberline forests support low numbers of nongame species and low population sizes compared with other habitat types in the Rocky Mountains and in contrast with other coniferous forest systems in North America (Raphael 1987). This, however, belies the importance of the whitebark pine ecosystem. If the cumulative values from watershed, recreation, range, species diversity, and habitat for non- game and big game species could be assessed in a compounding fashion, then the value of the whitebark ecosystem is better represented (Hann 1987). This ecosystem particularly gains in importance in management priorities when some of the value of one of the animals that uses it, the federally listed grizzly bear (*Ursus arctos*), is transferred to it.

The value of the whitebark pine ecosystem to wildlife, in terms of what specific site and stand conditions optimize its value for a given species, is often not well quantified. As a result, wildlife management programs specific to whitebark are generally not very sophisticated. A generic response of simply attempting to protect whitebark forests for the wildlife resource is typical and often sufficient. It serves as a good "umbrella" management objective. The lack of specific information and the fragile nature of subalpine forests makes caution in management an appropriate response. Shallow, poorly developed soils with low fertility, severe climates, and a short growing season make them more vulnerable to the mistakes of managers (Arno and Hoff 1989; Thomas 1987).

However, more specific information is often needed to assist managers in developing programs for managing whitebark for wildlife. As better information becomes available it can be integrated into three basic principles.

MANAGEMENT PRINCIPLES

First, even though the boundaries of the whitebark pine ecosystem and grizzly bear distribution do not directly overlap, the national priority given to the grizzly gives it a driving force in the broad topic of wildlife management in whitebark pine areas. Second, a great deal can be accomplished for the wildlife resource if management objectives for this resource are carefully integrated with the management objectives of other resources. Although not the ideal situation, this can be done using basic concepts of wildlife management without the precise knowledge of the optimum site and stand characteristics for each species. Third, in general the whitebark pine ecosystem represents only seasonally valuable range for wildlife. With this in mind, the whitebark pine ecosystem cannot be managed as an island for any species. In attempting to establish management objectives for a species that uses the whitebark pine ecosystem, all seasonally important ranges need to be considered.

For the practical application of these three principles, three species that use the whitebark pine ecosystem will be discussed: the grizzly bear, the Rocky Mountain bighorn (*Ovis canadensis*) sheep, and the Shiras moose (*Alces alces shirasi*). Our understanding of the specific habitat requirements of these (and other species) in the whitebark pine ecosystem is at different levels. When specific requirements are determined, they can be integrated into the three principles mentioned.

Grizzly Bears

The importance of whitebark to grizzlies is well documented (Kendall 1981; Mealy 1975). The unique relationship between whitebark, grizzlies, and red squirrels (*Tamiasciuius hudsonicus*) has also been documented (Kendall 1981; Mattson and Reinhart 1987). Mattson and Reinhart (1986) have taken our level of understanding further to describe the relationships between density and the probability of red squirrel midden use by grizzly bears, site and stand characteristics, and trends in squirrel activity and population levels. An understanding of these relationships is being fine tuned (Mattson 1989).

This information has provided us with a clearer understanding of what areas with whitebark specifically are important to grizzlies and why. In a management sense, this could conceivably assist in determining the location, timing, and appropriateness of vegetation manipulation—either timber harvest or prescribed burning. Reforestation through planting whitebark, as an additional option for vegetation manipulation to benefit grizzlies, can also be considered (McCaughey 1988).

Although this information is very useful by itself, it also has applicability in integrating recreation management with wildlife management. Mattson and Reinhart (1986) observed that the availability of nuts greatly influences numbers of grizzly/human conflicts and resulting management actions. Management actions were observed to be fewer during years of good nut production and higher when nut production was poorer. They stated that, in general, low pine nut production is positively correlated with high mortality rates for grizzly bears. It was their opinion that when nut production is assessed during July, the potential intensity of grizzly/human conflicts can be predicted. With an awareness of the location of the most productive areas for grizzly bears for foraging on whitebark pine nuts, managers can adjust recreation use patterns. With an awareness of the annual success of whitebark pine nut crops, managers can brace for trouble with increased patrols, tighter travel restrictions, or more public education. In this context, the whitebark pine resource suddenly becomes a very relevant topic at the field level of management.

Certainly, a management objective for meeting the habitat needs of the grizzly in the whitebark ecosystem would be to maintain or create site and stand conditions that optimize the area for the bear. However, there is another management objective that is overriding in its immediacy and in its demand for attention. It tends to permeate all management activities for all resources in grizzly country. Because of the grizzly's listed status and its propensity for conflict with humans, a wildlife management objective for the whitebark pine ecosystem (and any other area where the bear is present) is zero preventable grizzly bear mortalities. Time and dollars are invested in making attractants unavailable to bears, preventing bears from making the association between people and food, and avoiding conflicts between people and bears—all variations on the same theme of trying to keep the grizzly from an untimely death (USDA FS 1986). Accomplishing this is in one sense optimizing the habitat for the bear, although it does not meet the usual sense of the definition of habitat enhancement. The listed status of the bear and the value of the whitebark pine ecosystem to the bear make this an important management objective.

Bighorn Sheep

Bighorn sheep summer in and adjacent to timberline forests. They often migrate to and from winter ranges through these same forests and through subalpine forests as well. Wakelyn and Bailey (1983) summarized key habitat factors of bighorn sheep range. They included: (1) abundant, continuous forage to support a large dispersed group, (2) nearby escape terrain, and (3) good visibility. In habitats that afford good visibility, predator detection is increased allowing individuals to disperse further from escape terrain and more effectively use the forage resource. In addition, in habitats with good visibility sheep tend to form larger groups. In larger groups individuals spend less time alert and may forage more continuously under the comparative safety of the collective alertness of the whole group. Forest succession may degrade bighorn habitat by reducing the quantity and quality of available forage and by reducing visibility.

Bighorn seasonal ranges are connected by traditionally used migration corridors. These corridors are predictably adjacent to the best escape terrain. This is often along rocky ridges where whitebark is present. Good visibility along migration routes is equally important and can also be degraded by forest and shrub succession. Wakelyn and Bailey (1983) concluded that sedentary populations either lacking in additional seasonal ranges or suitable migration corridors have "bleak futures" as they are more susceptible to disease and predation.

Whitebark forests in advanced successional stages where visibility is poor and forage more limited due to the proliferation of other conifer species have progressed past the point of providing optimum habitat for bighorn sheep. Early successional stage timberline and subalpine forests are of more value to sheep. The influence of fire and its alteration of these forest types favor sheep. Gruell (1983) concurred that sheep, as a grass- and forb-eating herbivore without strong requirements for abundant cover, are favorably influenced by the results of fire. Therefore, a management objective for bighorn sheep in the whitebark pine ecosystem would be to maintain early successional stages, specifically in the timberline zone. Because of the low market value of timber in these areas and their general inaccessibility, particularly next to rocky escape terrain, timber harvest as a means of returning to early successional stages is not usually viable.

However, manipulation of timberline and subalpine forests with whitebark by fire is not a panacea for meeting the habitat requirements of bighorn sheep populations. Suitable summer range in or adjacent to the whitebark pine ecosystem is most often not the limiting factor.

Healthy populations (relatively large, mobile groups) need a variety of seasonal ranges linked by migration corridors. The year-round range of a bighorn may include up to nine seasonal ranges. Each migration corridor between seasonal ranges is potentially a weak link that can jeopardize a bighorn population. Forests with whitebark are only a part of a bighorn sheep population's range. The quality of winter range well away from the whitebark pine ecosystem is more often the issue. While management objectives for bighorn sheep in whitebark types should be to optimize security from predators and optimize available forage, they should be conducted with the awareness that areas with whitebark are only part of a more complex habitat. Careful coordination with other land use activities is critical in all parts of a population's range. This is particularly true because the winter range of bighorn sheep, unlike the summer range, is more easily reached by humans and so is more susceptible to degradation.

Shiras Moose

Moose are traditionally associated with early successional stages and deciduous browse species. However, Loope and Gruell (1973) observed that the moose population in northwestern Wyoming has increased with advancing forest succession. Gruell (1980) stated that moose numbers were low around the turn of the century when much habitat was in early succession with the influence of wildfires. Moose populations did not increase significantly until more advanced stages were reached 60 years or more after large wildfires. He attributed the increase to an increased availability of winter forage, especially subalpine fir. He indicated that subalpine fir appeared to be the primary and even exclusive diet in late winter. Subalpine fir has increased dramatically over a widespread area in the near absence of wildfires. Studies from other areas where tall growing deciduous trees and shrubs that reestablish rapidly after fire are well represented show moose benefiting from early successional stages. However, in northwestern Wyoming succession is slower, there are fewer tall deciduous shrubs and trees, and deep snows preclude the availability of browse present in early successional forests. Schladweiler (1973) found subalpine fir to be an important browse species of moose in southwestern Montana, particularly at higher elevations and in late-successional-stage forests. Stevens (1970) found relatively large numbers of moose in the Gallatin range wintering at high elevations in late-successional forests (spruce-fir).

Work being done on the Gardiner District of the Gallatin National Forest has resulted in similar conclusions (Tyers and others 1989). Moose in the drainages of the Yellowstone River on or adjacent to the northern winter range of Yellowstone National Park and the Gallatin National Forest spend most of the winter in late-successional forests. Their diet is primarily subalpine fir. The forests used are cover types (Mattson and Despain 1985): LP3—overstory of lodgepole pine with some Engelmann spruce, subalpine fir, and whitebark pine in the pole size class; an understory of small to large spruce and fir seedlings and saplings, 300 years plus post fire. SF—dominated by Engelmann spruce and subalpine fir in both overstory and understory; lodgepole pine, Douglas-fir, or whitebark pine may be present but are a minor stand component. WB3—dominated by mature whitebark pine and may also contain considerable Engelmann spruce, subalpine fir, or lodgepole pine; understory is a combination of Engelmann spruce, subalpine fir, and whitebark pine. DF3—ragged canopy of predominantly mature to overmature Douglas-fir but containing some Englemann spruce, subalpine fir, or whitebark pine in the pole-sized class, understory of small to large spruce and fir seedlings and saplings.

A common denominator in these cover types is the fact that they are late-successional stage forests with an understory of subalpine fir. A completion of the study and data analysis will further describe the microsites within those cover types the moose select. Density of subalpine fir saplings of a certain height will be important.

Another common factor with these cover types is that whitebark pine may be present, but as different age classes and in different quantities. Also, these cover types represent late-successional forests several hundred years removed from fire. In areas where whitebark is present in late-successional forests and moose are utilizing an understory of subalpine fir as a browse species, the return of these forests to an early successional stage through fire or timber harvest would be to the detriment of the moose.

Snow depth and consistency have an impact on moose use of winter habitats. Forests with closed canopies can be easier to travel in than open areas because of these variables (Jenkins 1985; Peek 1971). Telfer (1970) in New Brunswick reported late-winter moose activity largely restricted to dense conifer-dominated stands after the animals spent fall and early winter in more open stands. In Quebec, des Mueles (1964) found that moose also shifted to more dense types when snow accumulated to 77 to 86 cm. Peek (1971) found that shifts to more dense types occurred as a response to differences in snow hardness and density as well as depth. Work currently being done in the northern Yellowstone area (Tyers and others 1989) suggests that moose abandon the early winter foraging areas in willow communities in late January in favor of dense forests—often with whitebark pine in the overstory or understory. This is in response to contrasts in snow depth and consistency. In late winter dramatic differences exist in these variables in open areas versus dense forests. These open areas include early successional stage forests brought about by timber harvest or recent fire. Such areas show almost no use throughout the winter. Gruell's (1980) notion that deciduous browse is either unavailable because of snow depth, slow to appear, or of insufficient quantities holds true for timber sale units in the study area described.

A management objective for the Shiras moose in the whitebark ecosystem where snow depth and consistency and a lack of deciduous browse force an association between moose and dense forests would be to maintain winter range areas in late-successional stage and ensure the integrity of travel corridors. This would require close coordination with timber harvest activities where the two occurred in the same area.

DISCUSSION

I have attempted to demonstrate that, although our understanding of the habitat requirements of wildlife in the whitebark pine ecosystem is thought to be poor, we

still have guidelines available to us for establishing management objectives for the wildlife resource. These guidelines represent different levels of sophistication and can be expressed as follows (proceeding from the simple to the more complex): (1) establish management activities on the premise that the whitebark pine ecosystem is a fragile and finite resource that should be protected from consumptive activities; (2) establish management objectives based on three basic principles: the needs of the grizzly bear dominate, the whitebark pine ecosystem is seasonally important range to different wildlife species and cannot be managed as an island for any given species that uses this ecosystem, and management activities must be integrated; (3) management objectives can be established based on a knowledge of the specific site and stand characteristics that optimize the value of the area for a given species.

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RESPONSE OF VEGETATION TO LIVESTOCK IMPACTS ON GREEN FESCUE SITES IN THE WHITEBARK PINE ECOSYSTEM

Charles G. Johnson, Jr.

ABSTRACT

Subalpine grasslands have been important for mid- to late-summer grazing by domestic sheep. Operations centered at base ranches in the canyons of the Snake River and valleys surrounding the Wallowa Mountains of northeastern Oregon. A serious degrading of these rangelands occurred near the turn of the century when sheep production was primary and concern for the natural resources was secondary. Following World War II, sheep use markedly declined with a responding rebound by vegetation that covered the scars of land abuse.

Pioneering range scientists used subalpine areas of the Wallowas to learn grassland successional relationships. Arthur Sampson studied the Standley Allotment between 1907 and 1911; Pickford and Reid selected Tenderfoot Basin for their 1938 investigation of depleted green fescue range. Their initial photographic work has been periodically retaken along with interpretation of successional trend.

The primary plant associations utilized by sheep in the subalpine areas of the Wallowa Mountains were dominated by green fescue (Festuca viridula *Basey*). *Classifying vegetation based on the potential of the site to produce a climax dominant grass is simplified by the pioneering secondary succession work accomplished by earlier investigators. The continued monitoring of green fescue sites will enable land managers to interpret severity of use with resulting plant compositional and productivity changes.*

INTRODUCTION

> Every mountainous part of the West has its particular breed of mountain bunchgrass; thus, green fescue is the mountain bunchgrass of the Blue Mountain country of northeastern Oregon and southeastern Washington. Lambs fed on these ranges are famous for condition and the high market prices they command. Few sights are more pleasing to the eye than high knolls and ridges covered with a fine stand of green fescue. The rich green hue of the foliage contrasts strikingly with the bright bluish-purple heads (USDA 1937).

Green fescue (*Festuca viridula* Basey) plant communities are found in the subalpine fir and whitebark pine zones occurring in parks, on open slopes and ridgetops, and as a part of a savanna beneath open-growing trees (Reid 1942).

Green fescue communities generally occur in exposed portions of the subalpine forest above 6,000 ft elevation. These grasslands exist on relatively dry sites within a high-precipitation zone (over 35 inches ppt/yr) that have been created by excessive wind transfer of winter snows, exposing these slopes to dessication (Daubenmire and Daubenmire 1968). Deep, finely textured soils capable of high water-holding capacity help compensate for wind dessication promoting the fescue on exposed, open slopes (Weaver 1979). Therefore, they support grasses and forbs in the absence of trees except for occurrence beneath whitebark pine in a savanna. These sites are often droughty in late summer when intense storms can provide highly erosive winds and torrential rains can cause severe sheet and gully erosion.

The species occurs in southern British Columbia and Alberta, the northern Rockies of western Montana and Idaho, along the Cascadian crest in Oregon and Washington, in the Sierras from Mount Lassen to Yosemite, and in the Wallowa and northern Blue Mountains of northeastern Oregon.

The grass plants form a dense sod with an extensive root system penetrating to depths of 3 ft and greater (USDA 1937). In good ecologic condition, green fescue communities are characterized by almost pure stands of grass, a dense foliage cover, and interstitial areas occupied by fescue root crowns and litter (Reid 1941). The forb composition of late-seral green fescue communities is often less than 20 percent (Johnson and Simon 1987).

Green fescue is well adapted to the severe climatic conditions prevailing at these subalpine elevations. In late seral stands, green fescue can average over 500 lb/acre. Communities in mid-seral stages of succession often contain a greater forb composition, which can provide up to 1,300 lb/acre. Late-seral green fescue stands in the Wallowa Mountains average almost 900 lb/acre of total herbage production (Johnson and Simon 1987).

Besides being very productive, green fescue is highly palatable and very nutritious. Sheep have been the primary class of livestock to historically use these high-elevation grasslands. They habitually prefer forbs, but avidly seek the succulent fescue and tend to graze this herbage more closely than that of other grasses (Sampson and Chase 1927). The deep extensive root system provides a stabilizing force to thwart erosion from high winds

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and surface water runoff resulting from either rapid snowmelt or high-intensity storms. When degraded, green fescue loses its vigor, seedhead production is diminished, and seedling establishment is often poorer. The capability of green fescue communities to withstand trampling from heavy animal use is lessened. The result is an increase in forb and other graminoid composition coupled with a breaking down of the soil mat followed by rapid soil loss.

GRAZING IMPACTS—THE TENDERFOOT BASIN STUDIES

Tenderfoot Basin is located in the whitebark pine zone of the Wallowa Mountains at elevations ranging from 7,200 to 8,500 ft. By the turn of the century, the dominant green fescue communities were badly deteriorated from sheep abuse. Annual overutilization of the available forage from the practice of turning livestock onto the allotment too early in the season resulted in low plant vigor and a decline in vegetative cover. The Wallowa Mountains were used extensively as primary summer range for large sheep ranches. In the early part of this century, 380,000 sheep were estimated to have grazed annually in the subalpine portions of these mountains (Cole 1977). The Tenderfoot Basin area was selected by G. D. Pickford and E. H. Reid to study plant succession and effects of use on green fescue grasslands. A second area was selected for comparison where sheep use had been much lighter, resulting in a green fescue community of near-climax ecologic condition.

There were four 1,200-head bands of sheep grazing for 3 months in Tenderfoot Basin in 1916 with a carrying capacity of 6.4 sheep months/acre. By 1938, the area could sustain only 0.57 sheep for a month on an acre (Pickford and Reid 1938). The plant communities were characterized as having only 33 percent vegetative cover with needlegrasses dominating over fescue on pedestals resulting from severe soil loss (estimated at 428 tons/acre). Other sites were further degraded. Here vegetative cover was only 10 percent consisting of needlegrass six times more abundant than green fescue and dominated by perennial and annual forbs. Erosion pavement was prevalent between the pedestals. Soil loss was estimated at 927 tons/acre on these earlier seral sites (Strickler 1957).

In contrast, in near-climax stands, green fescue comprised 68 percent with lupine the only other associate. The grass sod was fairly continuous with no distinct hummocky appearance, exposed soil was less than 25 percent at the surface, and no erosion pavement was evident. This climax fescue grassland could carry 5.35 sheep on an acre for a month where the best stands at Tenderfoot Basin could only support 0.57 sheep (Pickford and Reid 1942).

SUCCESSIONAL CHANGE (1956)

Tenderfoot Basin was reexamined in 1956 following an 18-year period of lighter sheep use (Strickler 1957). The desirable forage species had increased in cover and production; most perennial forbs decreased in cover and vigor. Active erosion had ceased as desirable grasses began to colonize the erosion pavement. Pedestals were breaking down and depositing soil on the pavement, providing new growing sites for young grass plants. In 1938, the three major graminoids (fescue, needlegrasses, and sedges) produced an average of 630 lb/acre on the Tenderfoot Basin sampled sites. In 1956, the same sites produced an average of 1,530 lb/acre of these graminoids (Strickler 1961). Fescue cover increased from 11 to 32 percent over the time period.

What contributed to this reversal in succession? It was determined (Reid and others 1980) that accelerated erosion ceased and vegetative rehabilitation began when:

1. The number of sheep using Tenderfoot Basin was reduced;
2. A deferment period had occurred;
3. Allotment entry was regulated to coincide with range readiness;
4. Periods of nonuse occurred;
5. Sheep were permitted to graze freely;
6. Bedgrounds were used for only one night.

FESCUE DOMINANCE REESTABLISHED (1978)

After 40 years had elapsed from the period of overutilization, the Tenderfoot Basin study locations had responded with a new vegetative vitality that altered the community composition toward the climax stage of succession (Reid and others 1980). Total plant cover had continued to increase since 1956 under light impact from grazing animals. The needlegrasses, sedges, and forbs declined in percent composition. Green fescue had regained dominance over needlegrass in the established perennial bunchgrass locations and was more actively invading the bareground locations. Most pedestals had either collapsed or were less visible due to a "rounding" by the new vegetative covering.

The acceleration of change between 1956 and 1978 was principally created by the reduction in sheep months of grazing, deferment periods over the preceding 40 years, and the stabilizing period necessary for fescue seedling survival on the eroded soil. Another factor in the acceleration of change may have been increased activity by soil mycorrhizal fungi. Prior to that time continued soil disturbance restricted fungal formation.

MANAGEMENT OF SUBALPINE VEGETATION

The need to maintain foliar or litter cover is important to the protection of subalpine fescue sites. Utilization should be limited to 50 percent of the fescue plant; this would require a minimal stubble height of 3 inches (Pickford and Reid 1942). At this limit of utilization, sufficient seed stalks should remain for natural reproduction. Grazing should be limited to a 1- to 2-month season following fescue seedhead formation and ripening to allow for dissemination of viable seed.

Domestic cattle are injurious to green fescue communities. The weight of the animal creates severe erosive opportunities through displacement of the porous soils and separation of sod mats from trampling hooves. The fine-textured, porous soils are very susceptible to subsequent

wind and water erosion. Sheep, properly tended, should promote fescue by preferentially grazing forbs and tamping fescue seed with their hooves. The lighter animal can move rapidly across the slopes and maximize utilization of the rangeland as a whole much more effectively than cattle (Johnson and Simon 1987).

Most of the subalpine areas where green fescue and high-elevation Idaho fescue communities (Hall 1973) occur are managed as portions of the National Wilderness Preservation System. Grazing by commercial permit has declined and appears to be continuing in decline. The major management concern for subalpine herbaceous vegetation will continue to be generated by people. As our population increases and these higher elevation sanctuaries are sought by the recreating public, degradation could increase where people and their animals congregate. Populations of native and introduced wild ungulates, if allowed to increase unchecked, can create some of the same degradation problems as were encountered by investigators in the Wallowa Mountains early in the 20th century.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from Anonymous)—Do you think that grazing domestic stock will ever be excluded from public lands?

A.—Not in the foreseeable future. Domestic livestock grazing is still a viable use of the forage resources of our National Forests. In many bunchgrass-dominated plant communities, a grazing animal stimulates tillering and invigorates the grass stand to produce new growth. Old growth is consumed with a resulting reduction in the buildup of material conducive to rodent infestations, disease, and fire susceptibility.

Q. (from Anonymous)—What effect did the drought of the 1930's have on your sites? How much of the state of the 1938 stands depended on the drought?

A.—I'm not sure we can determine the role of climate on the state of green fescue rangelands 50 years ago. Certainly the major factor leading to the condition of the rangelands then was overgrazing by domestic sheep.

Q. (from Anonymous)—Are there situations in subalpine meadows where forbs are an indicator of a healthy situation? What's wrong with forbs? Where should they be growing?

A.—There is nothing wrong with forbs in subalpine plant communities. From the successional point of view, we see forb increase with degradation of green fescue grasslands and ultimate domination by forbs in very denuded areas. The concept of late-seral (near-climax) communities having nearly forbless stands dominated by perennial bunchgrass is proposed through work in classifying green fescue stands where stability has occurred over time. Forbs provide a diverse offering to the grazing resource. We may wish to manage for mid-seral stands where green fescue is strongly associated with a forb component. If we are managing for recreational use, forb abundance is often highly desired by our high-country users.

STREAMS, LAKES, AND FISH IN WHITEBARK PINE ECOSYSTEMS

Ray J. White

ABSTRACT

Not only do streams, lakes, and fish occur in the white-bark pine (Pinus albicaulis) *ecosystem, but the streams and fish are important to ecosystems lying downslope and extending out into the mountain valleys. Many of the lakes support significant recreational fishing, but few of the streams do, although they may serve as spawning, juvenile rearing, and refuge areas. The primary fishes of interest are salmonids, certain kinds of which seem better adapted than others to high-altitude streams. The streams here tend to be an extraordinarily harsh environment due to steepness, coldness, ice conditions, and nutrient poverty—but in some regions may have a more dependable water supply than those farther downslope. Avalanches, ice, snow, boulder control, vegetation, beaver, and disturbance by livestock grazing may often play important roles in shaping stream channels in these areas. Many of the high lakes of the United States Rocky Mountains have been stocked with trout, char, or grayling, many kinds of which are exotic to the regions or drainages. Many of these lakes no longer contain their prestocking-era faunal composition. The lakes that are deep enough often have substantial salmonid populations, but growth tends to be slow, owing to infertility, cold, and 7 to 8 months of ice cover. Those near hiking, pack-trip, or vehicle trails are commonly overfished, but many are so remote that this is not a problem.*

INTRODUCTION

Streams and lakes exist as distinctive aquatic subecosystems nested in and closely interconnected with a hierarchy of larger, primarily terrestrial, ecosystems, such as those defined by small drainage (catchment) basins and clusters of larger basins. In some drainage basins and ecosystems, whitebark pine (*Pinus albicaulis*) is the predominant tree. This may or may not mean they are whitebark pine ecosystems.

The stream and lake subecosystems perform in special ways that are surely affected by whitebark pine and the associated biota. It is likely that no one has studied characteristics of streams and lakes in relation to whitebark pine specifically. The plant communities of whitebark pine forests must influence the chemistry of soils, hence of surface and subsurface runoff water that feeds streams and lakes. Streams and lakes in the forest may supply food for various members of the animal community, namely herbivores, such as moose (*Alces americanus*), and carnivores, such as osprey (*Pandion haliaetus*), mustelids, and bears. It is well known that fish can be very important in the diet of grizzly bears (*Ursus horribilis*). They feed heavily on cutthroat trout (*Oncorhynchus* [formerly *Salmo*] *clarki*) from Yellowstone Lake that migrate into the lower reaches of tributary creeks to spawn in late spring and early summer, however researchers in Yellowstone National Park have no evidence that bears eat fish in creeks at still higher elevations (Reinhart 1989). Although beaver (*Castor canadensis*) may not use whitebark pine, within some parts of the forests, they may strongly influence vegetation, soils, water levels, fish, and wildlife habitat. At this stage of our knowledge it may be most appropriate to discuss general characteristics and functioning of streams and lakes that are at about the same range of altitude as whitebark pine and to raise questions and highlight potentially important issues based on general information.

For this paper, I not only have reviewed literature, but have discussed the subject with limnologists, as well as with fishery biologists from State agencies and the Forest Service, U.S. Department of Agriculture, in Montana and Idaho, who deal with waters in the whitebark pine range. Interesting and potentially useful information exists that is not in the literature because the observations are not from formal study but are largely subjective.

The assigned topic, "water quality and fish," was changed because water quality is only one of several important general aspects of aquatic ecosystems affecting their performance and their fish. Other key aspects are water quantity (for example, streamflow discharge and lake volume), physical structure of the water body, and temporal regimens of variation in water quantity, water quantity, and physical structure. All are interrelated.

Because the needs for protecting water quality are fairly well known, and because matters of water quantity are covered by Farnes (this proceedings), I will concentrate on physical structure and its effects on fish. To consider stream quality and lake quality in their totalities is often much more effective than focusing narrowly on water quality. I am fond of pointing out that even if the water of a stream or lake is pure enough for human babies to drink, and even if it is at the same time sufficiently nutrient-rich and of the right temperature for growing lots of organisms, still, it cannot harbor many fish of desirable size if the container is the wrong shape.

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The shapes of stream channels and lake basins are important to the suitability of these water bodies for other organisms as well. For example, the fineness of streambed texture (small-scale structure) can greatly affect the kinds and abundances of benthic fauna. Also, the steepness of side slopes of lake basins, as well as lake depth—hence darkness—can affect the abundance of rooted aquatic plants and all that depend on the plants.

What goes on in ecosystems containing whitebark pine, especially in regard to vegetation and soils, may greatly affect the shapes, water quantity, and water quality of streams and lakes. Conditions of the drainage basin's vegetative mantle will exert much control on inputs of water, sediments, and dissolved chemicals. Streambank vegetation is a major determinant of stream channel shape and of the stability of the bed and banks. In particular, the sloughing of trees and brush into channels forms jams and other large roughness elements that resist downward and lateral erosion of the stream and that provide hiding cover for fish and other orgainsms. There are obvious effects of drainage basin morphometry; slope steepness is important, as are the roles and effects of snow avalanches and landslides on the shapes and hydrology of streams and lakes.

In the sections that follow, I will discuss lakes separately from streams. One characteristic common to both types of aquatic systems and of special relevance within a forest is that, when not frozen, they have wet surfaces that catch small particles of organic debris. Of great importance to stream and lake ecosystems, particularly small ones such as found in alpine areas, is the amount of small debris from terrestrial vegetation—such as bits of bark and twigs, pollen grains, leaves, and needles—that enters and can be used by the aquatic biota. These fragments can be blown for great distances through the air and across surfaces of rock, ice, and crusted snow, but the wet surfaces of water bodies act as sticky traps for them. This material is then held within the stream or lake and does not soon, if ever, return to the terrestrial part of the larger ecosystem. Hence, streams and lakes receive far more allochthonous particulate organic input than would derive even from having a canopy of vegetation. In small headwater creeks in particular, the food web tends to be based far more on terrestrial organic detritus than on algal production (Vannote and others 1980).

The sport fishes adapted to life in high-mountain lakes are all salmonids—trouts, chars, and graylings. Before stocking was begun, the salmonids that naturally occurred in high-mountain waters within the range of the whitebark pine were the cutthroat trout, represented by several subspecies, each including many strains having special adaptations to local conditions; the arctic grayling (*Thymallus arcticus*); some varieties of redband or rainbow trout (*Oncorhynchus mykiss*, formerly *Salmo gairdneri*) west of the Continental Divide, and also on that side of the mountains, the river char known as bulltrout (*Salvelinus confluentus*). Few species of nonsalmonid fish occurred in high streams or lakes; sculpins (*Cottus* spp.), the longnose sucker (*Catostomus catostomus*), and the burbot (*Lota lota*) probably were the only ones. Stocked species have included cutthroat trout, arctic grayling, rainbow trout, brook trout (*Salvelinus fontinalis*—a char from eastern North America), golden trout (*O. aguabonita*) from California, and the European brown trout (*Salmo trutta*).

HIGH-ALTITUDE LAKES AND THEIR FISH

High lakes of the Rocky Mountains and other ranges on this and other continents are generally small, often locally numerous, have usually been formed in various ways by glacial action, and are always cold, thickly covered with ice and snow for most of the year, and relatively nutrient poor (Loeffler 1983; Rabe and Breckenridge 1985). The typical inaccessibility of mountain lakes to fish has meant that most were fishless, at least until people began extensive stocking.

In contrast to nearby streams, lakes now support almost all of the high country's recreational angling. On high Rocky Mountain trails, hikers or packtrippers who have fishing rods are almost always on the way to or from a lake, not a stream. Some people go into the mountains mainly for the fishing, but for many, that sport is incidental to other recreation. In the last few years, the proportion of mountain lake fishing that is incidental, as opposed to being the main objective, may have increased, according to the impressions of the few mountain lake anglers I polled on this matter.

By the late 1960's, overharvest of trout in wilderness lakes by backpackers was a major management headache for State of Idaho biologists. Therefore, the State's official informational booklet on mountain trails and lakes was discontinued, and now privately published trail guides may undermine that effort to reduce angling pressure (Gebhards 1988). Idaho's Sawtooth National Recreational Area has particularly heavy human use; lakes near trails are intensely fished, and remote lakes seldom fished. Outfitters are taking clients back into some of the remote lakes, and these are suffering problems caused by horse grazing.

Camping near lake shores may now be the foremost human use of alpine lakes, but fishing surely remains as an enhancement of the camping experience, as well as a major attraction . The plant-and-soil systems of the riparian zones of high lakes may be particularly fragile. It is obvious to all who have observed the effects of human activity, such as camping around high lakes, that damage to physical and vegetational conditions occurs as a result of trampling, wood-gathering, fire sites, waste disposal, and the use of pack animals. Chemical water quality of the lakes also can be affected by these activities (Taylor and Erman 1979).

In most high lakes of the Rocky Mountains, there would be no fishing had the fish—mainly trout but also grayling—not been introduced by humans. In the 1920's in Montana's Beartooth Range, for example, miners, packers, rod and gun club members, and government personnel began to stock fish in the mountains (Anderson 1984). For sustained fishing, repeated stocking was required because many of the lakes lacked spawning habitat. Most had no gravelly tributary or outlet streams, or lacked certain types of lakebed gravel formations. In the Beartooth

Range today, about 35 percent of the lakes contain fish, 25 percent lack fish but are probably capable of sustaining them, and 40 percent are unsuitable for fish (Anderson 1984).

The planting of trout and grayling in high lakes was often successful from an angling standpoint, when the lakes were relatively deep and nutrient rich. The practice was rather unsuccessful (fish grew poorly) in lakes that were too shallow or nutrient poor, or when, as was often the case, more fish were stocked than the food resources could sustain (Reimers 1979). The process of overcrowding and consequent stunting of salmonids introduced in high-mountain lakes also is common in the Alps (Pechlaner 1966, 1984).

Salmonid stocking may almost always have been a disaster for the pre-existing faunal community. In the few lakes having native populations of trout or grayling, the stocked trout of other species—or of other strains of the same species—would usually have exerted adverse competitive pressure (Moyle and others 1986). When the stocked species was able to breed substantially with the indigenous species, introgressive hybridization may often have eventually eliminated the former; this is common when rainbow trout are imposed on some strains of cutthroat trout (Behnke and Zarn 1976).

Not only do unmanaged high-mountain lakes tend to have few kinds of fish, if any, but, owing to recent (on the geologic time scale) formation of the lakes, poor accessibility, harsh climate, and low nutrient availability, the entire faunal community of such a lake tends to be poor, compared to lakes of similar dimensions at lower altitude. The typical natural, relatively simple, hence probably unresilient community, would have had some salamander, frog, or predatory invertebrate (insect or zooplankter) at the peak of the aquatic trophic pyramid—aside from water birds during the short, ice-free season.

When salmonids were suddenly thrust into such systems, they would within a few months or years deplete the invertebrates that were large enough to be of value to them (Pechlaner 1966, 1984; Reimers 1979). Predatory fish of any kind in ponds and lakes at any altitude become stunted (almost stop growing) when they become so numerous that the invertebrate population is kept size-selectively cropped down to the point that the only food organisms left are those so small that the fish's energy cost of capturing and eating such an organism exceeds the energy that can be gained from it. This process is so well known that the literature for it need not be cited. This was demonstrated in reverse when brook trout were transplanted from a densely populated mountain lake to a less crowded one and subsequently accelerated in growth (Rabe 1967).

Thus, especially in the nutrient-poor lakes so often found in alpine areas, the fish virtually eradicate the food supply, almost stop growing, and exist for years on the verge of starvation—which fish are good at, especially in very cold water. Perhaps in almost no high lakes, even if the supply of larger invertebrates has not been severely cropped off, do trout or grayling grow at rates that would generally be considered fast. This is because the water is continually so cold. Where food remains relatively plentiful, the slowly growing fish that survive eventually reach large size because in the cold they live much longer than in waters of normal temperature regimen.

The result in many high lakes has been extraordinarily large, long-lived trout. These are lakes that were rather lightly stocked, have been very lightly harvested, and are biologically productive. Examples of excellent fisheries in high lakes abound. A Beartooth Mountain lake accessible by a good but steep foot trail many kilometers long reportedly contained not only fair-sized cutthroat trout caught by anglers in summer, but also brook trout of 2 kg or more. The latter were apparently caught with regularity only in winter by very few fishermen using special bait and willing to wade through kilometers of hip-deep snow (Marcuson 1975). Some other lakes of that area yield cutthroat and brook trout that are commonly as large as 35 to 40 cm (personal observation of the author).

Greater lake productivity can be due to location in calcareous mountains and on south-facing slopes, as well as other conducive attributes (Johnson 1973; Rabe and Breckenridge 1985). Calcareous (limestone) formations are fossilized marine organisms and their products. Water flowing over and through such rock dissolves alkaline ions and other plant nutrients. The alkalinity also directly benefits trout and many other organisms by imparting near-neutral pH to the water and by buffering against swings in acidity and against toxicity of various dissolved metallic ions. As opposed to lakes of humid eastern North America, in which the limiting nutrient for biological productivity is usually phophorus, those of the arid West are most often nitrogen limited (Priscu 1985-87). High mountain lakes of the West appear to fit this pattern. In research now under way, most lakes of Montana's Beartooth Range are proving to be nitrogen limited. Fallout from the 1988 fires in Yellowstone National Park resulted in nutrient enrichment, as evidenced by microbial responses, in high, alpine lakes (Angelo 1989). In a sample of 10 high-mountain lakes in a once-remote wilderness area of California, there was significant positive correlation between percentage frequency of benthic plants and intensity of past recreational camping in the lake vicinity (Taylor and Erman 1979).

In the many nutrient-poor or overstocked high lakes, the fish also lead long lives, but starving, stunted, truly miserable lives, and do not reach large size. The classic account is that of a brook trout population stocked in a high Sierra Nevada lake, the last survivor of which lived into its 24th year, doubling the previous longevity record for the species. Its body length was only 25 cm, mostly accrued during its first 6 years of growth, 9 months of which were in a hatchery from which the lot was stocked at mean size of 6.6 cm (Reimers 1979). In various other types of waters, brook trout reach 25 cm in 2 to 3 years.

HIGH-MOUNTAIN STREAMS AND THEIR FISH

High-altitude streams are typically small, cold, and very steep with much shallow water rushing over beds of large stone. The steep reaches, however, often contain accumulations of boulders and large woody debris that form a stairstepped bed. Behind the obstructions, gravel

deposits serve as spawning beds. Just below the steps plunge pools occur, which provide fish with resting sites protected from swift current and predators.

The multifaceted benefits to fish habitat of having many large roughness elements (mainly boulders and logs) in streams and the important role of woody debris in creating such roughness have recently become apparent (Lisle 1981, 1986). Important among these benefits is the creation of hiding cover (visual isolation from predators and competitors) and eddies where current is slow enough to enable fish to maintain position without undue expenditure of energy. Where whitebark pine predominates, the contribution of its logs and limbs to streams is a question of interest that has probably not yet been investigated.

Streambed steepness is also occasionally interspersed with mountain meadows and swamp pockets where gradient is less, where gravel and finer sediments accumulate to form the streambed, and where pronounced meandering courses form, having pools at the bends and riffles between bends. Stream-dwelling salmonids are adapted to the features associated with stairstepping in the steep reaches and meandering in the low-gradient reaches.

The populations of resident trout in these small, steep, cold waters often attract little angling because the fish are generally small. Many of the streams, however, are considered to be very important to the fisheries of downstream rivers and lakes, not only because they supply water and nutrients, but because they serve as spawning grounds for larger fish that migrate from the larger, warmer waters. They also provide rearing habitat for young offspring. In western Idaho, bull trout and westslope cutthroat trout (*O. clarki lewisi*) predominate in streams above about 2,000 m; juveniles of steelhead rainbow trout and chinook salmon (*O. tshawytscha*) are the primary inhabitants at lower altitudes (Anderson 1988).

Fish in alpine streams face many problems, natural and human caused. Due to the vagaries of drought and spells of ample flow, trout populations in headwaters tend to fluctuate greatly (Erman 1986). Many parts of high-altitude streams freeze completely in winter, and their fish must move to other areas or perish, although those of small enough size can survive where the streambed is composed of stones that offer interstices leading to subsurface water. Slushlike anchor ice, which typically forms on winter nights and disappears the next day, also is a special hazard. Artificial sources of damage to high-mountain streams probably derive from almost any type of human activity that occurs in or near the streams and their riparian zones. Notable in the past was the near eradication of beaver from streams. At present, in addition to recreation, significant artificial factors include livestock grazing, logging, mining, and a variety of construction and maintenance activities associated with dwellings, roads, trails, power lines, telephone lines, pipe lines, water storage dams, and diversions for water supplies.

Beaver constitute one of the major natural habitat influences for stream fish in the Rocky Mountains—a beneficial influence in most cases. Their dams and ponds contribute importantly to the stairstepped stream profile and diversity of channel form and flow. The ponds also trap and store organic matter that would otherwise flush out of the system sooner and not be as available to stream (and terrestrial) organisms. Roles of beaver in stream ecosystem functioning were discussed by Naiman and others (1986). Whether beaver ever relate directly to whitebark pine apparently is not discussed in the literature, but beaver definitely extend their activity into the altitudes of the whitebark pine range.

In eastern Idaho, western Wyoming, and southern Montana, beaver are often abundant at 1,800 to 2,500 m (Platts 1989). In whitebark pine areas, they use willow for dams and for food, particularly for winter food caches. In summer much of their diet may be herbaceous plants, which tend to thrive at high altitudes better than in lower zones that have prolonged dry periods. Although willow brush tends to be small at high altitudes, it suffices for beaver dams, which can be low and relatively weak because (1) large floods do not occur in headwaters, (2) heavy snow cover prevents the winter ice layer from becoming as thick as at lower altitude, and (3) the beaver need not flood as large an area to reach sufficient food, owing to the availability of herbaceous vegetation (Platts 1989). Donald Anderson (1989) reports that beaver impoundments are important to Idaho salmon at altitudes of 1,800 to 2,000 m.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (Mike Merigliano)—If the exotic trout and other fishes are eliminated from the previously barren high-mountain lakes, would the original food chain reestablish itself in the original composition?

A.—This consideration, not covered in the brief oral presentation, is touched upon in the printed version. Referenced material indicates that populations of invertebrates—at least of some invertebrates—increase (and trout growth rates increase) as trout populations diminish. This is not to say, however, that the full species complement and proportional abundances of the community have been restored. Probably there has not been enough study for us to know whether full recovery of an original community ever takes place. One might expect some species that are highly vulnerable to predation by (and competition from) trout, that have low reproductive rates, and low interlake mobility, hence poor potential for recolonization, to remain absent for many years after disappearance of trout from a lake. In the absence of former components of the community, especially if they had been key species in the trophic system—or "keystone" species in other respects—the species that do recover would be unlikely to repopulate to the same relative abundance as before disruption of the community by the trout. The community could therefore not be said to have truly recovered.

SNOTEL AND SNOW COURSE DATA: DESCRIBING THE HYDROLOGY OF WHITEBARK PINE ECOSYSTEMS

Phillip E. Farnes

ABSTRACT

*Snow survey measurements have been made in and near whitebark pine ecosystems in the Western United States and Canada for over 50 years. Within the past 15 years, automated SNOTEL (**snow** survey **tel**emetry) sites have provided daily data on snow water equivalent, total precipitation, and temperature. This information, along with hydrologic relationships, is used to describe the various hydrologic environments occupied by whitebark pine. Variations in snowpack, snow water equivalent, annual precipitation, growing season precipitation, and potential water yield from these areas are presented. SNOTEL sites in the Western United States and similar sites in Alberta, British Columbia, and California that provide historic and current data on snow water equivalent, total precipitation, and air temperature in or near whitebark pine ecosystems are identified.*

INTRODUCTION

Whitebark pine generally occupies the higher elevation zones of western alpine watersheds (Arno and Hoff 1989; Little 1971). These areas are also the main water-producing zones. Snow courses and SNOTEL (**sno**w survey **tel**emetry) or similar sites have been established in these zones to monitor the seasons' snowpack and the primary source of the water supply. Data from these sites are also useful in evaluating the climatic and hydrologic regimes of whitebark pine.

SNOW SURVEYS

Snow surveys started in the West near Mount Rose, NV, in 1906 (USDA SCS 1988a). However, the first major expansion to all western States occurred in the mid-1930's, as a result of unprecedented drought and water shortages. There are now approximately 1,500 snow courses in the Western United States and 300 in Alberta and British Columbia. The record for manual snow surveys, which include both snow depth and snow water content, now exceeds 50 years at many locations. Generally, snow surveys are made three to five times each year. Many of these snow courses are located in areas occupied by whitebark pine.

Snow pillows were first installed in the early 1960's. These containers hold an antifreeze solution and are placed on the ground surface. The weight of the snow on the pillow is transferred to sensors inside a shelter and recorded with onsite recorders or telemetered, using radio equipment. Usually, snow pillows are 10 to 12 ft in diameter and are made of nylon reinforced neoprene. They provide a continuous record of snow accumulation and melt. Recording and storage precipitation gauges are also installed to quantify the total precipitation at these locations.

Snow pillows are a part of a system of SNOTEL sites that now number about 550 in the Western United States, excluding California (Barton 1975; McMillan 1981). All SNOTEL sites gather snow water equivalent, total precipitation, and air temperature daily. Other data such as wind speed and direction, solar radiation, and soil temperature are collected at a few of these sites. There are about 110 similar sites in California and about 12 in British Columbia and Alberta.

The SNOTEL electronics are currently being upgraded with microprocessors that can be programmed to select, accumulate, or average data. At sites with the upgraded electronics, daily maximum and minimum temperatures are being selected and the average daily temperature is being calculated using 96 daily observations.

While the primary use of these data is to forecast water supplies, they can also be used to evaluate the climatic regime of the whitebark pine.

There are approximately 110 SNOTEL sites or other snow measuring sites where both precipitation and snow water content data are gathered that coincide with whitebark pine ecosystems. While these sites occur in Alberta, British Columbia, California, Idaho, Montana, Nevada, Oregon, Washington, and Wyoming, as shown in table 1, the majority of these sites are in Idaho, Montana, and Wyoming.

Those wishing to access these data or those who have questions should contact the Soil Conservation Service, U.S. Department of Agriculture, (SCS) snow survey staffs in the western States (USDA SCS 1988b). Cooperators can access the SCS's Centralized Forecast System (CFS) in Portland, OR, using a computer and modem. Both real-time and historic data for snow courses and SNOTEL sites are available. Depth and snow water equivalent are available for snow courses. Daily snow water equivalent,

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Table 1—Sites in or near whitebark pine

State or Province	Number sites	Range of elevations	Range of average annual precipitation	Range of average maximum SWE
		Feet	.... *Inches*	
Alberta	6	6,960- 7,640	30- 43	17-31
British Columbia	5	5,540- 6,360	38- 58	16-36
California	8	9,800-11,450	30- 40	12-32
Idaho	18	5,560- 9,150	31- 88	22-71
Montana	32	5,930- 9,100	26- 85	10-50
Nevada	7	7,700- 8,800	24- 43	15-24
Oregon	9	5,315- 6,200	35-112	19-72
Washington	5	5,400- 6,500	51- 83	40-74
Wyoming	16	8,200-10,100	21- 48	9-33

precipitation, and air temperature are available for SNOTEL sites in Idaho, Montana, Nevada, Oregon, Washington, and Wyoming. In California, the Department of Water Resources is the responsible agency and can provide snow, precipitation, and temperature data. In Alberta and British Columbia, the Provincial governments can provide this information.

PRECIPITATION, SNOWPACK, AND WHITEBARK PINE

Data from these sites show that whitebark pine grows under a wide variation of average annual precipitations and snow water equivalents. Average annual precipitation varies from about 20 inches to over 100 inches. Average maximum seasonal snow water equivalents range from about 10 inches to over 70 inches (California 1987; USDA 1987 Annual Data Summaries for Idaho, Montana, Nevada, Oregon, Washington, and Wyoming; Alberta Environment 1986; Ministry of Environment 1985).

Some of the lower average annual precipitation amounts may be misleading because redistribution of snow by wind may create a more favorable moisture environment for this species. This is most evident in some areas in Wyoming where snow at higher elevations is redistributed into drifts around tree stands. These drifts increase soil moisture, modify soil temperature, and hold soil moisture to near field capacity levels later into the season. This redistribution of snow may also create a favorable microclimate for reproduction in these lower precipitation areas.

The amount and distribution of precipitation between complete snowmelt and fall freezeup may be the most critical factor in whitebark pine survival and growth. Since soils in whitebark ecosystems generally have low water holding capacity, the frequency of summer rain may be as important as the quantity of precipitation that falls. Also, condensation is very common in these altitudes during summer months, and it is possible that this enables these trees to lower their daily transpiration.

The date snowpack melts to zero at SNOTEL sites in or near whitebark pine areas averages mid to late June. In California, Nevada, and Oregon, the average date of complete melt can be as early as mid-May. Snowmelt at the higher elevation sites in Wyoming continues into mid-July on the average.

Average precipitation that occurs after all the snow has melted and prior to fall freezeup, usually in early September, varies from about 3 to 5 inches. However, a few sites show precipitation as high as 7 to 8 inches during the snow-free season. Very little runoff is generated from the precipitation falling during this snow-free period as most of the summer's precipitation enters the soil profile and subsequently is used by the vegetation or evaporates.

Lack of significant moisture over long periods may stress the whitebark pine since the water holding capacity of the soils is quite low. The amount and distribution of this precipitation could also be related to the success of pine nut production. Sustained growth and good nut production are probably optimum when there is adequate moisture available from the soil throughout the entire growing period for 2 or more consecutive years.

WATER YIELDS AND WHITEBARK PINE

Whitebark pine areas are usually in the heavier precipitation zones in areas that have scanty vegetation and on soils that have a low water holding capacity. These areas

yield large per-unit runoff within any given watershed; the per-unit runoff is generally exceeded only by that from the alpine areas above timberline.

In areas of western Montana that have an average annual precipitation of 30 inches, about 35 percent of this annual precipitation (about 10 inches) eventually flows out of the watershed as streamflow. The efficiency increases to about 60 percent in the 70-inch precipitation zones where about 40 inches eventually become streamflow (Farnes 1978). Snowmelt runoff from whitebark pine areas occurs late in the runoff season and is some of the most valuable water for irrigation in drainages not having reservoir storage. The runoff from these high elevations usually coincides with large irrigation demands in June and July.

Management of these stands would probably have little effect on water yield or peak flows for any given watershed. The snow at high elevations is not usually melting or is melting very little when the peak flows are occurring from these watersheds. Any change in snow distribution related to management of existing whitebark pine stands would not cause any significant changes in peak flows at downstream locations. Removal of significant volumes of timber would reduce evapotranspiration and could result in small increases in runoff until regeneration is established. In windy areas, snow redistribution could be altered by stand management and could affect the runoff. Selective thinning in denser stands would increase snow throughfall and would increase the water yield from snowmelt. However, in most situations, the costs for such treatment would probably exceed any benefits accruing from the increased runoff. Each situation would need to be evaluated on its specific merits and objectives to determine whether it was economically and environmentally feasible to attempt to manage any given stand of whitebark pine for water yield enhancement.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from Wendel Hann)—Is there a difference in the way whitebark pine catches and shades snow compared to subalpine fir?

A.—In younger stands where shapes are similar, for example, tall and slender, the response is similar. As the crown of the whitebark pine begins to expand, there is a much larger surface area that intercepts snowfall and the shade of the larger crowns encompasses a much larger ground surface area that reduces melt rates of snowpacks in the shaded area.

RECREATION IN WHITEBARK PINE ECOSYSTEMS: DEMAND, PROBLEMS, AND MANAGEMENT STRATEGIES

David N. Cole

ABSTRACT

Whitebark pine ecosystems are an important element of many of the most spectacular high-elevation landscapes in the western United States. They occupy upper subalpine and timberline zones in the prime recreation lands of the Cascades, the Sierra Nevada, and the Northern Rocky Mountains. This paper explores the nature of the recreational opportunities that the whitebark pine ecosystem provides and the demand for those opportunities. Important management problems are described, as are strategies for minimizing problems and optimizing recreational opportunities.

Dispersed backcountry recreation is particularly important in whitebark pine ecosystems. Maintenance of natural-appearing landscapes is a critical management objective with this type of recreational use. The principal management challenges are to (1) provide opportunities to enjoy the landscape but concentrate and contain use wherever it regularly occurs, (2) design transportation systems and facilities to blend with the surroundings, (3) strive to improve site rehabilitation techniques, and (4) minimize the obtrusiveness of other forest uses.

RECREATION DEMAND AND OPPORTUNITIES

Most whitebark pine ecosystems are remote and inaccessible by road (Arno and Hammerly 1984). Consequently, the most common recreational activities are dispersed backcountry pursuits, such as backpacking, horsepacking, hike-in fishing, photography, nature study, and contemplation. A large proportion of these ecosystems—probably well over one-half—is protected as Wilderness, under the authority of the Wilderness Act, which expressly prohibits mechanized equipment, such as four-wheeled vehicles, motorcycles, snowmobiles, and even mountain bikes. This limits the range of recreation activities in most places.

Demand for outdoor recreation is great in whitebark pine ecosystems. The Cascades and Sierra Nevada are close to the population centers of the Pacific Coast, and the Northern Rocky Mountains are an important vacation destination. Wilderness acreage in these areas is abundant and large numbers of wilderness visitors are attracted to whitebark pine ecosystems. Eight of the 10 most heavily used wilderness areas in the United States have substantial amounts of whitebark pine (fig. 1). Within these wilderness areas, visitors are frequently attracted to these high-elevation forests. Visitors commonly hike or ride through lower elevations up to the higher elevation forests and meadows that are their primary destination. This tendency can be illustrated using data collected in the most popular portion of the Eagle Cap Wilderness, in the Wallowa Mountains of northeastern Oregon. In that area, about one-third of the landscape consists of whitebark pine forests, associated subalpine meadows, and spruce-fir forests in which whitebark pine is a component. However, 46 percent of the trail miles and 78 percent of the campsites are located in these ecosystem types (Cole 1977). Most wilderness visitors want to spend most of their time in these places.

The reasons why wilderness visitors are particularly attracted to whitebark pine ecosystems have not been studied. Four attributes of these ecosystems that likely attract large numbers of dispersed recreationists are esthetics, diversity, ease of hiking and camping, and good fishing. These landscapes are highly esthetic. Views of rugged peaks are often spectacular. At these elevations the peaks look close and the open stand structure provides more frequent vistas than the denser forests of lower elevations. Stunted whitebark pines and sun-bleached snags are highly attractive, particularly silhouetted or bathed in late evening's alpenglow.

Whitebark pine landscapes are also unusually diverse. Meadows and rock outcrops are frequently as abundant as the forests and invite exploration. Creeks babbling through the meadows and the wildflowers that fill the meadows add to the diversity and interest of these areas. So do glacial features, such as cirque lakes and waterfalls, that cascade over glacially carved steps. The relatively open and highly diverse landscape invites cross-country travel and dispersed camping. It is relatively easy to hike off trail and to find attractive campsites away from heavily trafficked places.

Finally, the fact that whitebark pine ecosystems frequently occupy glacially carved landscapes means that cirque lakes are common features. These lakes attract visitors both as an esthetic and logical destination area and because they frequently offer good fishing. Fishing is an important wilderness activity for many visitors. In many wilderness areas, more than one-half of all visitors spend some time fishing (Lucas 1980). Fishing quality is

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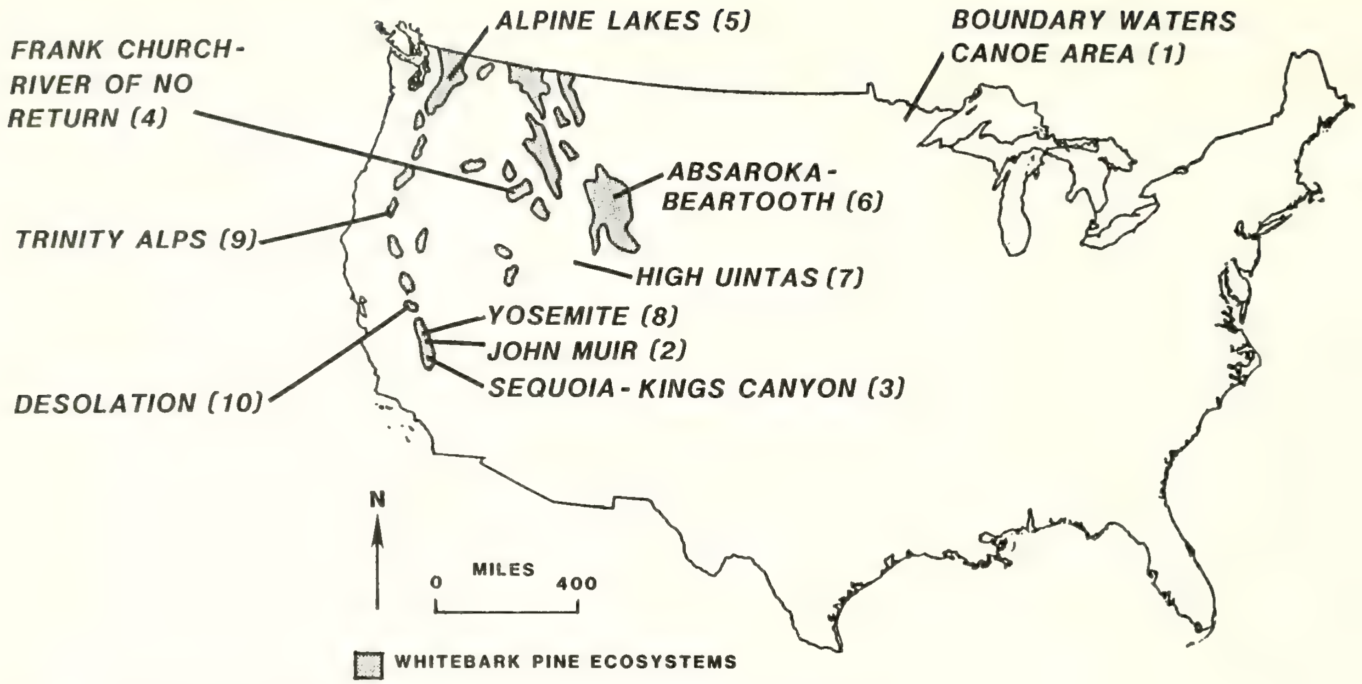

Figure 1—Eight of the ten most heavily-used wilderness areas in the country are in places with whitebark pine ecosystems. Numbers in parentheses are the rank of each wilderness area in terms of amount of use.

often an important consideration when selecting a wilderness destination and goes a long way toward explaining the popularity of whitebark pine ecosystems.

While backpacking, horsepacking, hiking, and fishing are probably the most common recreational opportunities that whitebark pine ecosystems provide, other types of recreation also are pursued. In the few places where roads access whitebark pine forests, scenic driving, picnicking, and roadside camping occur. The Tuolumne Meadows-Tioga Pass area in Yosemite National Park is a good example of a popular place offering this style of recreation. Snowmobiling and off-road-vehicle driving are well-established in some places and mountain biking is growing greatly in popularity. Demand for these experiences is high, again because of esthetics, diversity, and fishing. However, these opportunities are limited by road access and are not as unique to these ecosystems as is backcountry recreation. Finally, downhill and cross-country skiing occur in whitebark pine forests, but are not especially common there.

One theme common to all of these recreational pursuits is the importance of scenic quality and a landscape that has not been greatly altered by man. This latter concern is explicit in wilderness, where the Wilderness Act (P.L. 88-577) directs management to preserve wilderness such that it "appears to have been affected primarily by the forces of nature, with the imprint of man's work substantially unnoticeable." Scenic qualities and an environment that contrasts with civilization are important motivations for visiting wilderness (Lucas 1985; Stankey and Schreyer 1987). I would hypothesize that these motivations are also important to recreationists outside wilderness and more important in whitebark pine ecosystems than in most other ecosystems.

A major management concern, then, should be to minimize the evidence of human use. This means minimizing the impacts caused by recreational use and sensitive design of transportation routes and facilities to accommodate recreational use. It also means minimizing the obtrusiveness of other forest uses, such as timber harvesting, grazing, and mining.

COMMON MANAGEMENT PROBLEMS

The most common problems that recreation managers face in whitebark pine ecosystems are resource degradation and crowding as a result of intensive recreational use. Trail and campsite degradation, packstock impacts, development of user-created trails around lakeshores, litter, and loss of solitude are all significant problems in many places (Washburne and Cole 1983). These problems are not unique to whitebark pine ecosystems, but they may be particularly pronounced due to the popularity of those landscapes.

Two studies have evaluated the susceptibility of whitebark pine ecosystems to recreational impact. In the Eagle Cap Wilderness, campsite impacts in whitebark pine forests were pronounced. The undergrowth vegetation, primarily grouse whortleberry (*Vaccinium scoparium*), is quite fragile; the mean vegetation loss on the central part of campsites was 94 percent. This compares, for example, with neighboring sedge (*Carex nigricans*) meadows where the mean vegetation loss on campsites was only 40 percent (Cole 1981).

Dale (1973) studied trails in whitebark pine, lodgepole pine, and spruce-fir forests of the Lee Metcalf Wilderness, in the Madison Range in southwestern Montana. Trails in whitebark pine forest were not particularly deep, but they tended to be unusually wide, particularly when subjected to heavy use. Factors that might contribute to wider trails here include (1) rocky soils that tend to cause users to spread out, (2) sandy soils that are readily displaced laterally, and (3) open vegetation that makes walking side-by-side easier. Generally, the suitability of whitebark pine forests for trails appears to be good to moderate, while suitability for campsites is moderate to poor.

Two problems that are particularly pronounced in whitebark pine ecosystems are the impacts associated with the collection of fuelwood for campfires and widespread proliferation of user-created trails and campsites. Collecting and burning wood in campfires is a common practice in most wilderness areas. In popular places this practice leads to large areas denuded of all downed wood and extensive damage to standing trees, both dead and alive. Damage to trees, from broken off lower branches to felled saplings and hacked snags, presents obvious evidence of human impact. A forest floor totally devoid of downed wood also looks unnatural to many visitors. In addition to these esthetic impacts, there are undoubtedly ecological changes that result from this practice. Recent research suggests that removal of large woody residue on and in the soil may have serious consequences. Large decaying wood plays an important and irreplaceable role in the ecosystem—for example, in water and nutrient conservation and as a substrate for biological activity (Franklin and others 1981; Harvey and others 1979).

These problems are likely to occur wherever fuelwood consumption rates exceed the rate at which downed woody material is produced. Problems are particularly likely in whitebark pine forests because productivity is relatively low and consumption is often high, due to the popularity of these places as destination areas. In a few study areas in the Sierra Nevada, for example, Davilla (1978) found that whitebark pine wood litter production was very low compared with that of lodgepole pine and mountain hemlock. This led him to recommend that fuelwood never be collected in forests where the dominant tree is whitebark pine. In many national parks campfires are prohibited at higher elevations; however, campfires are seldom prohibited in wilderness areas administered by the Forest Service, U.S. Department of Agriculture (Washburne and Cole 1983). While it is very common to discourage the use of campfires (and encourage visitors to use stoves), it is uncommon to differentiate among ecosystems in terms of their productivity and therefore the importance of not having a campfire (Cole in press).

Another problem that is particularly pronounced but not unique to whitebark pine forests is the proliferation of campsites and user-created trail systems in popular destination areas. Proliferation reflects heavy use, ease of cross-country travel, and the large number of potential campsites in these ecosystems. For example, all campsites were inventoried in a 325-acre area around two popular lakes in the Eagle Cap Wilderness. More than 200 campsites were found (fig. 2). Virtually every site around Mirror Lake with the potential for camping showed some evidence of use. Also, the fact that recreational use in the area was spread over a very large number of sites did not mean that impact on these sites was negligible. More than half the campsites had experienced a moderate to great loss of vegetation (Cole 1982). In addition to all these campsites, numerous informal trails branched off from the constructed trails to other campsites and to circle the lakes. Created by users, many of these trails are poorly located and prone to erosion.

Impact problems are exacerbated by the difficulty of rehabilitating damaged recreation sites in whitebark pine forests. Rehabilitation is required wherever excessive or inappropriate use has occurred or whenever management objectives change. Much of the current rehabilitation work in wilderness is focused on campsites close to lakeshores. In the past, few wilderness areas had specific objectives about appropriate campsite locations; today objectives frequently stress maintaining lakeshores in as natural a condition as possible. It is also common to rehabilitate braided trails and trails that have been relocated either because they were inadequately constructed or poorly located.

Without assistance, trails and campsites in whitebark pine ecosystems will require decades—if not centuries—to recover. For example, campsites in a lodgepole pine-whitebark pine forest around heavily impacted Bullfrog Lake in Kings Canyon National Park were closed to overnight use in 1961. After 17 years of closure, soil compaction levels had returned to near-natural levels. Litter depth and volume, however, remained substantially below those found in undisturbed forest. Tree damage, vegetation loss, and user-created trails remained pronounced, although recovery had begun. Tree mutilations were often covered over with new growth and some of the trails were being recolonized (Parsons 1979; Parsons and DeBenedetti 1979).

Attempts to assist site rehabilitation in these ecosystems are challenging. It is difficult to effectively close sites to use, and without effective closure sites are not likely to recover (Cole and Ranz 1983). Even where assistance has been effective in establishing an initial plant cover on damaged sites, recolonization of the entire site may be slow. For example, the success of transplanting was followed over a period of 5 years on two campsites in the Eagle Cap Wilderness. Mean vegetation cover on these two sites increased from 6.3 and 10.8 percent in 1979 to 7.3 and 12.3 percent in 1984. This compares with a mean vegetation cover of about 60 percent on undisturbed sites. Most of this increase was a result of the original transplanting of plugs. While most transplants survived, they had not spread and did not contribute much to a gain in vegetation cover (Cole 1986).

A final problem is disposal of human waste. Toilet facilities are seldom provided in whitebark pine ecosystems because use frequently is dispersed and facilities often are considered inappropriate. Where heavy overnight use occurs, camping areas can be littered with feces and toilet paper. In addition to being an esthetic problem, this can pose a health hazard. It is difficult to clearly demonstrate a cause-and-effect relationship between inadequate disposal of human waste and disease;

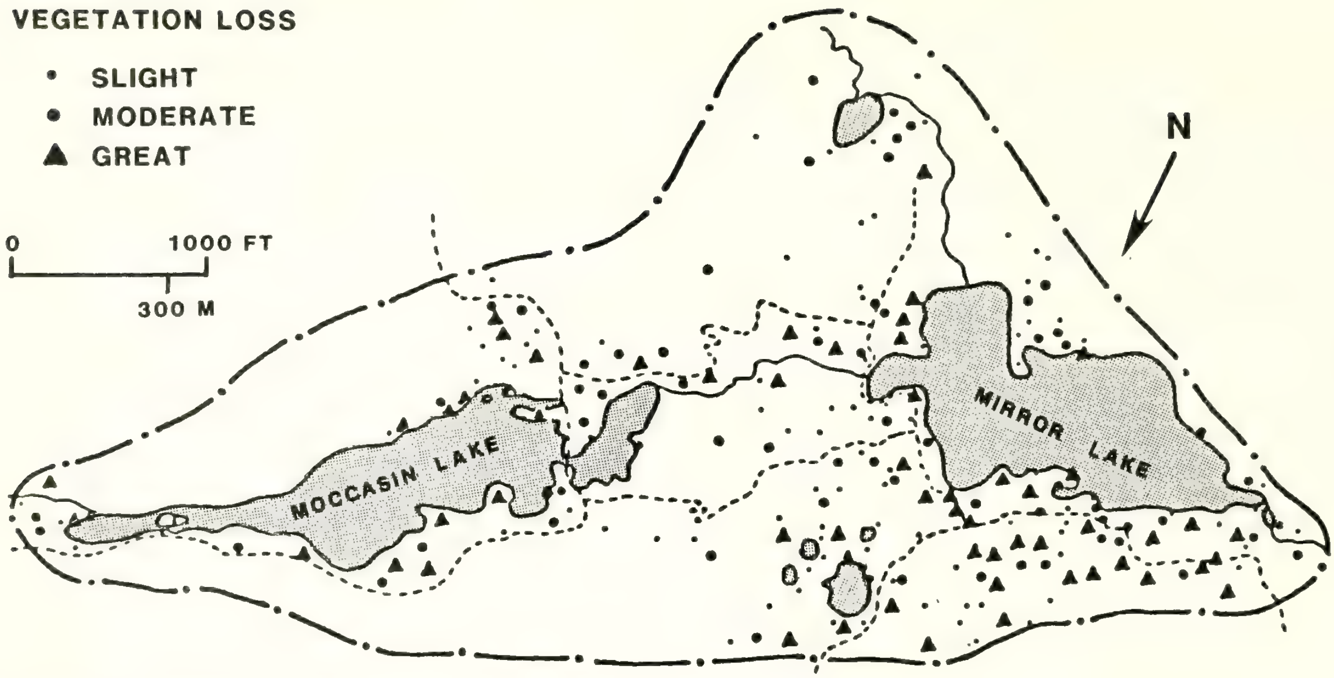

Figure 2—The distribution and degree of vegetation loss on campsites around Mirror and Moccasin Lakes in the Eagle Cap Wilderness, OR.

however, there is some evidence that *Giardia* spp. are more abundant in surface waters of frequently used recreational areas (Suk and others 1987). *Giardia* contamination is now a common problem in whitebark pine ecosystems.

MANAGEMENT STRATEGIES

Maintaining a natural-appearing landscape is the key to recreation management in whitebark pine ecosystems. Recreationists visiting these places expect to see little evidence of human use and impact. Characteristics of whitebark pine forests that make this difficult are inherently low productivity and low resilience. Once damage occurs, recovery takes a long time. Given the popularity of these places with backcountry recreationists, this low resilience means that management must be especially proactive. Management must strive to avoid problems rather than deal with them after they have occurred.

Four challenges face managers of whitebark pine ecosystems seeking to optimize recreational opportunities. First, it is important to concentrate and contain recreational use wherever it regularly occurs. Extremely low recovery rates make it imperative to minimize the number of places that are disturbed by recreational use. This is accomplished by confining as much use as possible to established trails and campsites. Overlooks should be designed to contain use and, if necessary, managers should harden heavily trafficked surfaces. Wilderness visitors should be encouraged to stay on constructed trails and use well-established or even officially designated campsites. Where packstock use is allowed, facilities for concentrating impact in small areas (for example, hitchrails or corrals) should be provided. The consequence of not pursuing this strategy is proliferation of impacts—a mistake that will require decades and centuries to correct.

Second, transportation systems and facilities can increase recreational opportunities in these ecosystems. Scenic byways and overlooks can add greatly to the enjoyment of motorized recreationists. Well-constructed trails, hitchrails, and toilets can add to the enjoyment of backcountry recreationists. Sensitive design is important, however. Cut slopes visible for miles—whether along roads or trails—are intrusive and detract from the natural environment. The challenge is to make certain that transportation systems and facilities blend into the natural-appearing landscape. This is particularly true inside wilderness, where the general philosophy is to provide facilities for purposes of safety and resource protection, but not visitor convenience.

The third challenge is to improve our ability to rehabilitate damaged sites. More experimentation with rehabilitation methods is needed. Rehabilitation efforts need to be documented and monitored; successes and failures need to be communicated to others. One example of a step in the right direction is a new rehabilitation program begun in whitebark pine and other ecosystems in Yosemite National Park. Experiments with seeding, nursery propagation, transplanting, and a variety of cultural treatments are under way. A controlled trampling experiment was conducted to evaluate the resistance of individual plant species and plant communities to trampling. Rehabilitation success is being monitored and results are being published in reports (Hadley and Moritsch 1988). Similar efforts are needed elsewhere.

The fourth challenge is to minimize the obtrusiveness of forest uses other than recreation. Timber harvesting, domestic livestock grazing, and mining are uses that can leave obvious disturbances on the landscape and detract

from the esthetics of these places. Where these uses occur, every effort should be made to separate these uses from recreational uses. Buffer strips along trails and roads can screen places where disturbance is evident. Trails can also be rerouted away from these places. Grazing can be limited to times and places where recreational use is low.

A CONCLUDING REMARK

A final challenge I might mention is the challenge I experienced in trying to write this paper. Information on recreational opportunities and problems in specific ecosystem types is sorely lacking. Consequently I had few concepts or data to work with and no precedent to follow or even build upon. Biologists seem to have conveniently ignored recreation management, preferring to concentrate on management of more tangible commodities. Recreation managers and researchers too frequently ignore the unique opportunities and constraints that each ecosystem presents. Better cooperation between these two groups is needed to effectively manage whitebark pine and other ecosystems.

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TIMBER MANAGEMENT AND TARGET STANDS IN THE WHITEBARK PINE ZONE

Jimmie D. Chew

ABSTRACT

Regardless of the mixture of land management objectives, quantification of the type of stands that will meet these objectives, target stands, is needed. Quantification of target stands is essential as the starting point for the diagnosis of treatment needs and to achieve consistency over time in the interpretation of a given management direction.

To facilitate quantification of target stands a U.S. Forest Service Regional form has been developed. This form provides one format for identifying various essential attributes.

For many resource objectives the desired conditions include the aggregate conditions of a number of stands in a given area over time. A Data General computer program has been developed to assist with the summarization and graphic representation of many stands projected over time by the Stand Prognosis Model. The summary and representation can be linked to key attributes that are descriptive of the target stands or to area conditions.

INTRODUCTION

Timber management can mean many things to different people. Within the whitebark pine (*Pinus albicaulis*) forest types of the Northern Region, Forest Service, U.S. Department of Agriculture, the activities that we usually associate with timber management will generally be done with little or no emphasis on sustained production of wood products.

Instead of identifying our management activities in the whitebark pine zone as timber management, it is more appropriate to refer to them as forest management: the application of our knowledge of silvics and forest ecology to create and maintain the types of stands that will meet our management objectives over time.

NEED FOR TARGET STANDS

The desired future condition that we refer to when we talk about implementing National Forest plans has to be considered at both the level of the individual stand and their aggregates across the forest. For all of our management objectives we need stands that will provide the desired conditions over time. How can we utilize our knowledge to ensure that we have such stands? How can we get from plans to the desired type of stands on the ground? How can we communicate with different resource managers over time about the type of stands we need? How can we achieve an adequate degree of consistency in the application of a given management direction between National Forests within a Region?

The use of site-specific evaluations of present and future stand conditions and the description of characteristic stands that meet Forest plan objectives are necessary to answer these questions. An essential part of being able to transfer our management objectives to the ground is to quantify what types of stands are needed to meet these objectives. Only by a comparison of an existing stand to a target stand can we devise a treatment or determine if no treatment is appropriate. All too often a treatment is prescribed simply because it is possible to use it; not because it is needed to modify existing stand conditions to achieve long-term management objectives.

REGIONAL FORM FOR TARGET STANDS

To assist in the quantification of target stands the Northern Region has provided a standard format: Regional Form R1-FS-2470-24 (12/86). An example of its application has been taken from the Lewis and Clark National Forest in Montana (tables 1 and 2). The management objective addressed by these two target stands is for "timber production and livestock grazing." Each target stand represents the application of this resource objective to a specific set of habitat types each one featuring a different tree species and different density levels over time.

Target stands have not been defined for all ecosystems and resource management objectives, specifically not for whitebark pine. Nevertheless, we can identify some of the questions that must be answered to formulate a target stand for meeting important management objectives in whitebark pine ecosystem. For an objective of producing cones for grizzly bear food what should the stands be like? Do we want stands that are all whitebark pine? Or should they be a mixture of species? Should they have uniform spacing of trees, or clumpy spacing? How long will it take the stand to start producing an adequate number of cones for food? Will the stand need to be thinned to remove natural regeneration of spruce and subalpine fir in the understory? How do stands in the Gallatin National Forest compare to those in the Flathead National Forest in regard to these questions. Answers to these questions

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Table 1—Target stand description

Development stage	Age	Trees per ac	Basal area	QM dia	Structure	Height	Species	Growth	I&D	Forage	Remarks
Seedling	0-15	300-2000	-	0-1	Single story	0-8	LP	-	Dwarf Mstoe minor occurrence	B-400 H-100	DF, S-acceptable
Sapling	15-30	500-1600	-	2		8-25	LP	10		B-300 H-75	Begins providing game hiding cover
Pole	31-50	400-780	70-210	5		25-50	LP	20		B-200 H-50	
Imm. saw	51-70	200-300	130-240	8		50	LP			B-200 H-50	
Mature saw	71-110	200-300	180-240	10		65	LP	30		B-200 H-50	

MANAGEMENT AREA: MA-B
HABITAT TYPES: Abla/Vasc [730], Abla/Libo-Vasc [663], Psme/Libo-Caru [292]
PRIMARY RESOURCES: Timber and Livestock Grazing

Table 2—Target stand description

Development stage	Age	Trees per ac	Basal area	QM dia	Structure	Height	Species	Growth	I&D	Forage	Remarks
Seedling	0-20	200-1700	-	0-1"	Single story	0-4'	DF	-	Budworm Low, Root Rot Mod 15% Area	B-400 H-600	
Sapling	21-40	200-1200	-	2		5-25	DF	3	SBW Low RR - Low 5% Area	B-300 H-450	
Pole	41-70	200-700	40-140	6		25-30	DF	20	SBW Low RR-Low	B-200 H-300	
Imm. saw	71-100	200-400	80-175	9		30-50	DF	44		B-200 H-300	
Mature saw	101-130	150-280	100-180	11		50-55	DF	30		B-200	

MANAGEMENT AREA: MA-B
HABITAT TYPES: Picea/Sest [460], Abla/Clps [770], Psme/Juco [360], Psme/Spbe [340]
PRIMARY RESOURCES: Timber with Livestock Grazing

are needed to quantify target stands that will meet our management objective of providing cones for grizzly bear food. Target stands for all other management objectives in the whitebark pine zone also need to be developed.

NEED FOR ANALYSIS OF STAND AGGREGATES

The desired future forest condition goes beyond what we describe for the individual stand. Creating a 5-acre stand to provide cones as food may be meaningless if it is the only such food source within an entire area. As we look at areas, they should be a collection of individual stands. As there is variability in the types of stands we can create, there is variability in how these stands respond to treatments over time. Evaluations of existing and future conditions over an area need to be as site specific as we can make them. This is perhaps more critical within the whitebark pine ecosystems than in many other forested ecosystems. Many of the presentations at this symposium have stressed how slowly whitebark pine ecosystems recover from impacts. Instead of using average responses over time, the Stand Prognosis Model (Wykoff and others 1982) allows us to generate site-specific values. We can evaluate our ability to meet given resource objectives in terms of the development of specific stands within a given area. The Northern Region has

linked a Data General graphics package with the Prognosis output to provide area summaries for resource attributes. For example the acres within different stand structural stages can be displayed for specific future decades (fig. 1). The changes in these attributes are stand specific based upon stand projections that will change with various treatment scenarios.

In terms of whitebark pine forests and the grizzly bear food management objectives discussed above, we can assess specific stand attributes such as blister rust status, crown ratio, tree height, and stand density for their influence on cone production. We can produce graphs similar to figure 1 to represent the effect of our management choices on acres in various cone production stages over time (fig. 2 and 3). By projecting the subsets of stands relating to the different cone production stages of figure 2, we can develop a picture, decade by decade, of the efficiency of management in achieving our chosen desired future conditions. An example is shown in figure 4.

Other resource objectives might be given priority within the whitebark pine zone—for example, watershed enhancement. As in the approach outlined above, needed information would be developed to describe desired stand conditions that define target stands for achieving the water resource goals. Similarly, stand and area projections would be aggregated for the present and for future time periods to guide decisions and provide benchmarks for monitoring management performance.

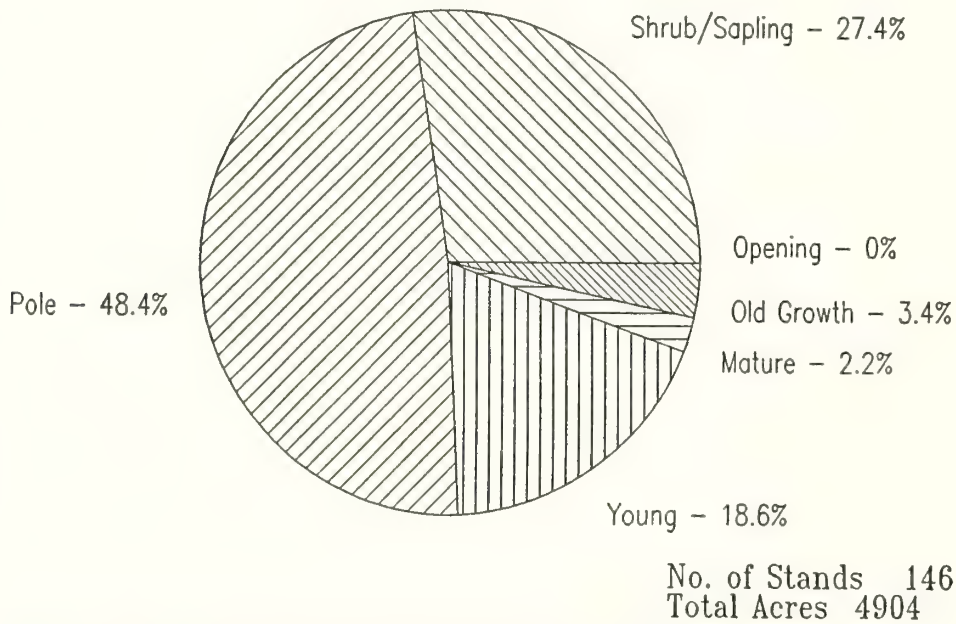

Figure 1—Stand structure stages of whitebark pine stands for wildlife habitat of the Gallatin National Forest for decade starting in 2021.

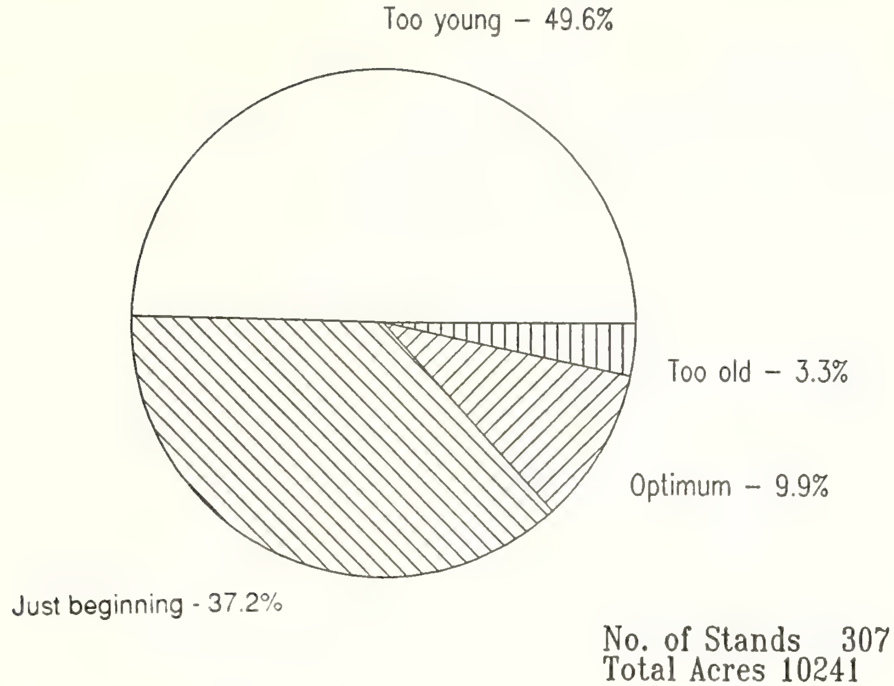

Figure 2—Projected percent of whitebark pine stands in various stages of cone production for the decade starting in 1990.

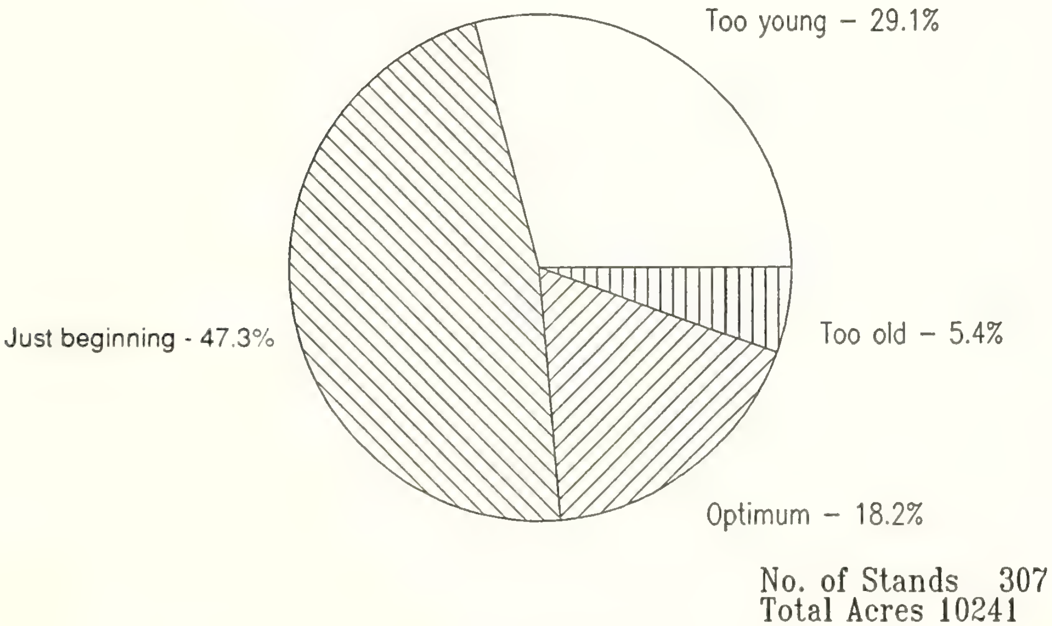

Figure 3—Projected percent of whitebark pine stands in various stages of cone production for the decade starting in 2020.

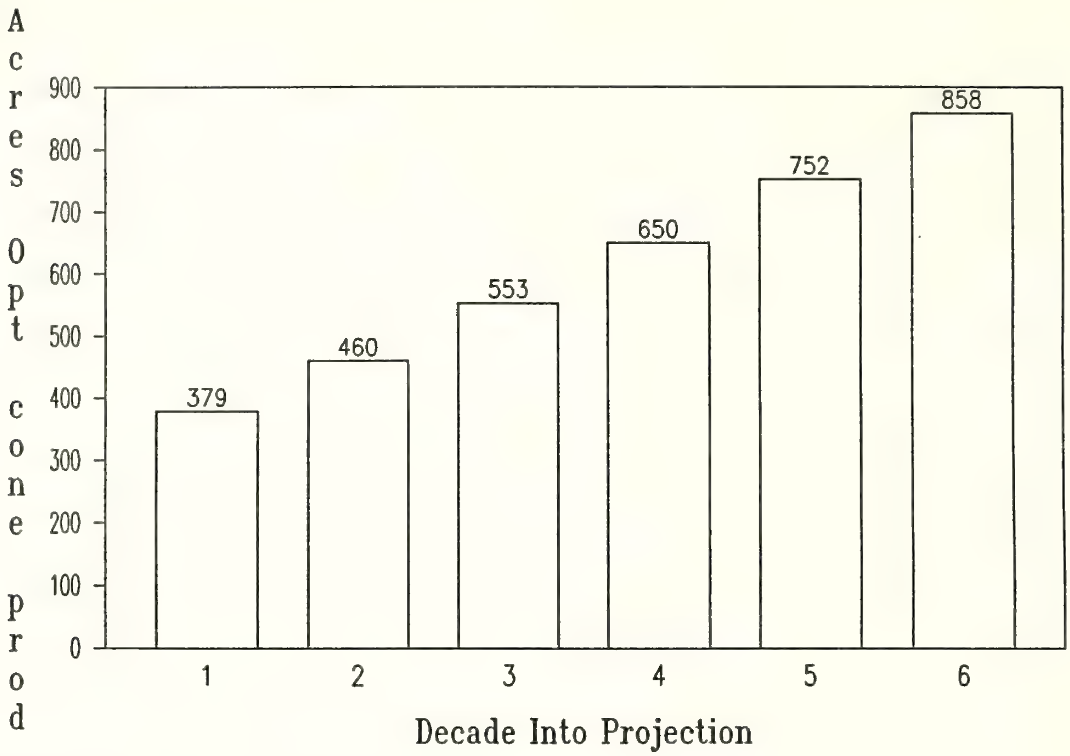

Figure 4—Projected acres of whitebark pine that will be optimum for whitebark pine cone production by decades. Projection is for 147 stands, 4,940 acres.

SUMMARY

Whether our management objectives are for watershed management, timber production, wildlife habitat, visual management, or any mixture of these resources, quantification of target stands is essential. Quantification of target stands provides the starting point for the diagnosis of treatment needs and consistency for the many resource managers involved in the interpretation of a given management direction over time. Without the quantification, it becomes difficult to monitor and judge the success of vegetative treatments and to rationally modify them to ensure meeting management objectives.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from Earle F. Layser)—Is it not presumptuous for us to assume we can set objectives for these high-elevation forests? Do they not by their very nature dictate their own objectives?

A. The very nature of these forests sets limitations and defines potentials. What would be presumptuous would be that we, at this time, assume we know all there is to understand concerning the limitations of these high-mountain ecosystems.

THE ROLE OF GENETIC DIVERSITY IN WHITEBARK PINE CONSERVATION

Peter F. Brussard

ABSTRACT

Whitebark pine, like most other coniferous trees, has high levels of genetic variation. This has been demonstrated for allozymes, and can be inferred for recessive deleterious genes as well. The current levels of genetic diversity in different populations of whitebark are determined to a large extent by their history and degree of isolation. Populations consisting of many contiguous or semicontiguous stands will have the highest amounts of heterozygosity. Small, geographically isolated, populations will have the least because of the strong influence of founder effects and restricted gene flow. If events occur that reduce current levels of gene flow in whitebark pine populations, levels of inbreeding are likely to increase. This will result in increased expression of deleterious recessives which, in turn, will reduce rates of survivorship and reproduction. These events can be particularly critical in populations already challenged by parasites, disease, or climate change.

INTRODUCTION

Consideration of genetic factors is critical in developing a management plan for any species because genetic variability is important for both short-term population fitness and long-term adaptation to changing environmental conditions. As the effects of global warming become apparent during the next half century, both factors are likely to become extremely relevant to conservation planning (Peters 1988; Peters and Darling 1985). Unfortunately, populations may not begin to show symptoms of genetic decline until the F_2 generation; for long-lived species like whitebark pine this seems to be an impossibly long time frame. However, this also means that decisions made now regarding genetic management will have important consequences for the resource many years in the future.

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GENETIC VARIATION IN OTHER SPECIES OF PINES

At this writing there is no published survey of genetic variation in whitebark pine (*Pinus albicaulis*). However, a recent review by Ledig (1986) pointed out that genetic variation in conifers in general and pines in particular is usually quite extensive, although there are some notable exceptions. Allozymes (polymorphic proteins) have been surveyed in 24 species of *Pinus* at between 4 and 59 loci per species. The proportion of these loci found to be polymorphic (P), under the criterion for polymorphism that the most common allele must occur in a frequency of less than 0.95, averages 0.53 ± 0.25 and ranges from 0 to more than 0.90 per species. The mean heterozygosity (H) for these species, calculated over this same range of loci, is 0.17 ± 0.09 and ranges from 0.0 in Torrey pine (*P. torreyana*) to 0.36 in loblolly pine (*P. taeda*) (data taken from table 1 in Ledig [1986]).

The average values for P and H in pines are higher than for most other plants and animals. For example, average P and H in vertebrates are 0.17 and 0.05, in invertebrates, 0.38 and 0.11, and in plants, 0.26 and 0.07, respectively (Nevo 1978). Although estimating levels of variation in entire genomes from the relatively small number of loci typically used (15-40) in the studies from which these figures are derived may be weak from a statistical standpoint (see Mitton and Pierce 1980), allozyme variants are generated and lost by exactly the same processes that generate and erode other kinds of genetic variation—mutation, drift, and selection. Thus, it is likely that species of pines with high levels of allozyme variability would also tend to be rich in other kinds of genetic variability. This seems to be true as well for polygenic traits such as growth rate, growth form, and wood characteristics and for genetic loads (Ledig 1986).

While certain types of genetic variation are important for both short-term population fitness and long-term adaptation, other variants, especially when occurring in homozygous form, may be deleterious. These deleterious alleles are referred to collectively as a population's genetic load, and expressed genetic load can significantly depress the population's overall levels of fertility and viability. Genetic load in conifers is often high; for example, depression in embryo viability following inbreeding is commonly reported (Namkoong and Bishir 1987). Ledig (1986) reported that embryonic lethal equivalents (recessive lethals that if dispersed among different embryos would cause, on average, one selective death) range from 0.3 to 9.4 per zygote and average 5.2 in eight species of *Pinus*;

the usual range is 1 to 4 in other plants, humans, and fruit flies. It should be noted that the total genetic load is actually much higher in pines because much additional mortality occurs after germination.

The high levels of genetic variation typical of pines are a consequence of many aspects of their life histories and reproductive biology. Most populations are exposed to heterogeneous selective pressures along major environmental gradients of elevation, exposure, and soil types. Timing of pollen release usually promotes outcrossing, and wind pollination provides opportunities for long-range gene flow. Furthermore, pines are long-lived and accumulate large numbers of somatic mutations; these mutations are transmitted to succeeding generations when somatic tissue is converted into germinal tissue. Ledig (1986) believes that this high mutational load drives the breeding system to outcrossing, which in turn protects all forms of genetic variation. The resulting high genetic load is expressed only under extreme inbreeding. The suggestion by Namkoong and Bishir (1987) that many of the genes that depress embryo viability in conifers may represent unique mutants, which will be eliminated by selection, is consistent with this idea.

Ledig (1986) has also summarized the patterns of distribution of genetic variation in various pine species. In general, he found that species of limited range have little variation, while widely distributed species tend to have more. However, there are many exceptions. For example, loblolly pine is wide ranging and highly variable, while red pine (*P. resinosa*) has a wide range and almost no detectable variation. Western white pine (*P. monticola*) is genetically uniform across most of its range, but is highly variable in California. Torrey pine is found only in two small populations, both of which lack genetic variation, but each population is genetically unique. Great Basin bristlecone pine (*P. longeava*) has a highly fragmented range, but it maintains high levels of variation with 90 percent of the total variation in the species found in any one population. Clearly, the current levels and distribution of genetic diversity in these species are complex functions of the species' dispersal history, population size, and degree of present range fragmentation.

GENETIC VARIATION IN WHITEBARK PINE

No survey of genetic variation has yet been done for whitebark pine throughout its range (McCaughey and Weaver, this proceedings), although such a survey is badly needed. A few relevant data are available, however. Furnier and others (1986) reported polymorphism at 9 out of 12 enzyme systems (75 percent) (or for 11 out of 20 presumed loci—[55 percent]) examined by electrophoretic techniques in two populations from Alberta. Linhart and Tomback (1985) used allozyme data to determine the genetic composition of multitrunked individuals in populations from Colorado and Wyoming. Their paper provided enough raw data for me to make an estimate of heterozygosity of 0.32 for the trees in one clump, although the small number of loci (N=4) and individuals (N=5) involved, plus the strong probability that all the individuals in the clump are siblings or half-siblings, make this estimate very tentative. Even with these limited data, however, it appears that whitebark pine has ample genetic variation, perhaps even more than the average for pines.

Because of its bird-mediated seed-dispersal mechanism, whitebark pine populations are likely to have a genetic structure different from those of wind- or gravity-dispersed species. Some data exist on this structure within clumps of trees, among clumps within populations, and among different populations. Furnier and others (1987) and Linhart and Tomback (1985) reported that clusters of two to 12 trees consist of at least some genetically different individuals. Weaver and Jacobs (this proceedings), however, present data showing that some clumps result from basal branching of the same genetic individual. Thus, trees with more than one trunk may consist either of a single genotype or more than one genotype (termed multitrunk trees and tree-clusters respectively by Tomback and others [this proceedings]). However, these differences cannot be determined without genetic examination.

Some of the individuals within tree-clusters are likely to be closely related because nutcrackers often gather and cache together seeds from the same parent tree. This was confirmed by Furnier and others (1987), who found that individual trees in a cluster were genetically more similar to each other than they were to trees in neighboring clusters. Further evidence is provided by Tomback (in press), who found that seed caches contained both related and nonrelated seeds and estimated with simulations that 73 to 93 percent of the caches contained two or more sibling or half-sibling seeds.

The close relatedness of trees within clumps evidently does not extend to clumps within stands. Furnier and others (1987) showed that individuals in neighboring clumps were not any more similar genetically than were individuals in distant clumps. Tomback and Linhart (1989) point out that such a pattern would be expected in a bird-dispersed species; one bird may disseminate seeds from a stand of trees to different areas, and within these areas, more than one nutcracker, each with seeds from different stands, may cache. Thus, gene flow among contiguous or semicontiguous stands of whitebark pine is probably rather widespread, resulting in large, diverse, and relatively homogeneous populations over fairly large areas due to the large home range of its dispersal agent and its wind pollination system.

Genetic heterogeneity probably increases on a larger geographical scale, however. Within its range, the distribution area of whitebark pine is highly fragmented, and gene flow is no doubt much less common among these units than within them. Furthermore, many small, isolated populations were probably established as a result of long-distance seed dispersal by nutcrackers (Wells 1983). Such establishment would lead to strong founder effects in these populations, and gene flow among them would be sporadic and uncommon. The net result of this fragmentation is likely to be a complex of genetically

differentiated units within the main body of the species' range and highly heterogeneous and genetically depauperate populations in areas outside the main Rocky Mountain and Sierra Nevada cordilleras. Smith (this proceedings) presented data that support this supposition; he found appreciable differences in the frequency of genes coding for xylem resin monoterpenes between populations in Nevada, California, and Oregon.

GENETIC FACTORS AND WHITEBARK PINE CONSERVATION

The goal of conservation genetics is to maintain populations large enough to keep levels of inbreeding low and to maintain high levels of heterozygosity. This is not only because there is reasonable evidence that supports the idea that heterozygosity at certain loci leads to increased fitness, but also because even moderate inbreeding can cause large increases in the expression of a population's genetic load. This increased expression of lethal equivalents and other deleterious recessives generally leads to reduced vigor and reproductive output, and the population becomes more susceptible to various stresses such as insects, disease, or climate change. Thus, large reductions in stand size or even extensive fragmentation of existing large stands—especially to the extent that medium-range seed or pollen dispersal patterns are seriously disrupted—may eventually result in a general decrease in population fitness for the remaining trees due to increased levels of inbreeding. As fitness decreases, reproductive success may decline appreciably, and this may eventually result in the population's extinction.

How large must populations be to prevent such genetic problems? Levels of inbreeding and the rate of loss of genetic variation are determined by a population's genetically effective size, not by its census size. Effective population size can be thought of as the number of individuals actually contributing genes to the next generation. This number is a complex function of spatial structure, age structure, variance in breeding sex ratio, variance in reproductive success among individuals, and fluctuations in population size over time. Needless to say, there are no data on effective population sizes in whitebark pine, but many aspects of the species' biology suggest that it may be small relative to total population numbers. For example, most populations are highly age structured because of episodic recruitment. Spatial structuring of related individuals and seed caching by nutcrackers may result in a high variance in progeny survival, and previous disease epidemics or insect outbreaks may have resulted in substantial population bottlenecks.

Genetic problems are likely to be more severe in small, isolated populations. These populations will be lower in heterozygosity and more inbred due to founder effects and reduced gene flow, and as a consequence they may face rapid extinction when exposed to stressful conditions. However, a few of these populations may have survived previous bouts of inbreeding, become purged of their genetic loads, and developed local adaptations with high survival value.

A survey of genetic variation throughout the range of whitebark pine is a necessary first step for formulating a genetic management plan for the species and for identifying populations of high conservation concern. Next, long-term plans must be made to preserve these populations where they occur. Reliance on botanical gardens, test plantations, seed storage banks, DNA libraries, and other similar techniques for the preservation of genetic diversity in this or most other tree species is too uncertain and far too costly (Ledig 1989). Stand preservation will involve the conservation of the entire whitebark pine ecosystem, including, particularly, a healthy population of nutcrackers. Fortunately, whitebark pine populations are concentrated at high elevations, which are generally the areas most often preserved as wilderness or national parks. Thus, while loss of genetic variation may be less of a problem in whitebark pine than in some of its congeners whose habitats coincide with more immediately profitable land uses, loss of seed sources from blister rust and population senescence related to fire suppression may well result in a declining genetic base for the future.

ACKNOWLEDGMENTS

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from Ron Lanner)—Since squirrels cause eventual death of most whitebark seeds on trees in closed mixed stands, should effective population size be adjusted to emphasize the importance of open-growing trees that maximize nutcracker harvest?

A.—Yes. This phenomenon will increase the variance in progeny contribution to the next generation and result in a substantial decrease in the ratio of genetically effective population size to census size.

Q. (from Dick Baker)—Would you recommend crossing isolated populations to preserve genetic diversity?

A.—Outcrossing is one way to replenish depleted genetic variation and decrease the level of inbreeding in isolated populations. However, outcrossing can also disrupt coadapted gene complexes that confer adaptation to local environments and consequently result in loss of fitness similar to that caused by inbreeding depression. This phenomenon is called "outbreeding depression." While there are no long-term deleterious consequences of outbreeding depression over the span of several generations, it can greatly increase the chance of population extinction during early generations if it is severe. Thus, outcrossing is not a universal panacea, especially in long-lived organisms such as whitebark pine.

Q. (from Dick Baker)—Whitebark pine has many disjunct populations, much like Great Basin bristlecone pine. Yet, genetic diversity seems to be much greater in whitebark pine, implying much longer isolation. Any idea why?

A.—I am not sure what you mean by "genetic diversity" in this context. If you mean genetic diversity in the sense of heterozygosity, Great Basin bristlecone has an H of 0.33 and a P of 0.79 (here P is calculated somewhat differently from the values presented in my paper), very near the high end of the scale. While an accurate H estimate for whitebark pine is currently unavailable, my very rough calculation of 0.32, along with P estimates of 0.55 to 0.75, puts it in the same ballpark as Great Basin bristlecone—certainly not very much greater.

If you mean "genetic diversity" in the sense of intrapopulation differentiation, once again accurate comparisons are not possible. It is true that Great Basin bristlecone has little genetic differentiation among its populations; the reason for this is to be found in its past history. This species occurred in essentially continuous stands throughout the Great Basin until about 12,000 years ago. Now it is reduced to remnant populations on mountaintops. Since these populations apparently have not experienced severe bottlenecks since the last glacial period, they have retained high amounts of intrapopulation variation. The present isolation of these Great Basin bristlecone populations evidently has not lasted long enough for much differentiation to occur among the remnant populations.

However, as I have suggested above, there is likely to be more differentiation among isolated populations of whitebark pine. This is because many of these populations probably originated from a few founding individuals carried to distant suitable habitats by birds. These founders would carry only a sample of the genetic diversity of the parent population with them, and the small post-establishment genetically effective population size would result in numerous fixations and losses of alleles by genetic drift. Thus, I predict that many isolated whitebark pine populations will be low in intrapopulation variation and high in interpopulation variation.

Q. (from Diana Tomback)—The dispersal of seeds by nutcrackers—a very mobile disperser—adds complexities to whitebark pine genetics. How would this affect conservation strategies for the species?

A.—Events that result in the reduction of nutcracker-mediated seed dispersal may have important genetic consequences of conservation concern. For example, widespread mortality in large whitebark pine populations from blister rust or pine beetle epidemics may leave only small, isolated fragments alive. These remaining fragments stand a good chance of becoming increasingly inbred if pollen flow and nutcracker visitation stop or decline appreciably; this in turn may lead to lowered fitness and perhaps eventually to extinction.

Likewise, small, isolated populations of whitebark pine probably receive some gene flow through occasional nutcracker-mediated seed dispersal. This trickle of gene flow may be enough to prevent a significant loss of genetic variation and extreme inbreeding in these populations. If nutcracker numbers decline, or if the species undergoes a range shift because of climate change, these populations will lose their only source of gene flow—with the consequences outlined above.

FIRE BEHAVIOR CHARACTERISTICS AND MANAGEMENT IMPLICATIONS IN WHITEBARK PINE ECOSYSTEMS

Richard J. Lasko

ABSTRACT

Fire is a significant element of alpine timberline ecosystems in the Northern Rocky Mountains. Fire behavior in these ecosystems is influenced by topographical, meteorological, and vegetative conditions that are characteristic of the alpine timberline. These characteristics and their relationships to fire behavior are analyzed.

INTRODUCTION

Managers are faced with a variety of challenges in the stewardship of high-elevation forests and timberlines in the Northern Rocky Mountains. The diversity of microhabitats and their distribution on the landscape in the alpine timberline compound the difficulties of prescribing management programs to achieve resource objectives. Success in these endeavors depends upon a clear understanding of the ecological processes that define the ecosystem. The ability to predict the behavior of fire, and its effects, is prerequisite to the management of any system where fire is a major ecological process.

The occurrence of fire in the alpine timberline in the Intermountain West is well documented (Forcella and Weaver 1977; Hawkes 1980; Heinselman 1985). Charred wood was found in the duff surrounding 300-year-old spruce in potentially fire-resistant, high-elevation cirque basins in northwestern Montana (Bigler 1976). Lightning is the primary cause, although, human-caused fires can enter the alpine timberline from lower elevations; or be introduced into this zone as human-ignited prescribed fire.

It is difficult to apply the concept of fire frequency to the alpine timberline because of the variety of microhabitats that occur. If fire regimes are characterized in this zone, they are usually described as having fire return intervals of 50 to 300 years (Arno and Hoff 1989). Both low-intensity and high-intensity fire have been documented in this zone (Billings 1969; Lasko 1987).

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Accurate prediction of fire behavior depends on the skill and knowledge of the user and the degree of uniformity, or lack of uniformity, of the fuels and environmental conditions (Rothermel 1983). Although fire occurrence at the alpine timberline is amply documented, there is a lack of recorded observations of fire behavior. Characteristics of the microhabitats of this zone define fire behavior potentials and effects. Successful management of fire at the alpine timberline requires recognition of the microhabitats and an understanding of the ecosystem processes that led to their establishment.

THE FIRE ENVIRONMENT

While each microhabitat is unique in a microclimatological sense, broadscale climatological features are applicable to the alpine timberline. These general climatic attributes define the limits of fire in this zone. Climates of the alpine timberline are commonly described as having long, cold winters and short, cool growing seasons. Precipitation generally increases with elevation (Baker 1944) and quite frequently occurs as snow.

Relative Humidity—Diurnal patterns of relative humidity in the alpine timberline differ significantly from those in valley bottom sites (Furman 1978; Hayes 1941). In contrast to the valley bottom sites where humidities can often reach values of 80 percent or greater under frequent summer night-time inversion conditions, humidities seldom exceed 50 percent at the alpine timberline. This factor contributes to the drying of all fuel size classes, including the duff layer, thus increasing the ignition potential and length of the daily burning period.

Snowpack Influences—Distribution, depth, and duration of snow cover have significant effects in determining the patterns of vegetation on the landscape and the environment for the drying of fuels. Deeper snowpacks do not directly correspond to moister fuel conditions, especially in large-diameter fuels (McCammon 1976). However, deeper snowpacks increase the duration of snow coverage of fuels and vegetation, resulting in shorter growing and decomposition periods. Drought conditions, wind ablation, or early removal of snowpacks by warm spring rains can increase the amount of time that fuels are exposed to the drying conditions of the atmosphere, thus lengthening and increasing the severity of the fire season at these high-elevation sites.

Fuels—Microclimatic conditions associated with alpine timberline do not encourage the decay of woody fuels. Downed trees that had been killed by fire were still present on a timberline site in Colorado 160 years after the fire (Billings 1969). Fuel inventories conducted in northern Idaho and Montana indicate that forested alpine timberline zones are characterized by accumulations of large-diameter downed and dead woody fuels. These inventories have indicated an average of 2 tons/acre of small-diameter materials (0.25 to 3 inches in diameter) and about 9 tons/acre of material over 3 inches in diameter (Fischer and Clayton 1983). Fuel loadings are expected to increase in northwestern Montana as a result of *Pinus albicaulis* mortality resulting from mountain pine beetle (*Dendroctonus ponderosae*) and white pine blister rust (caused by *Cronartium ribicola*).

Windfield—Alpine timberlines are directly influenced by regional air mass phenomena and associated gradient winds. Windspeeds often increase at high-elevation sites during night-time hours (Baughman 1981). The location and orientation of each particular site influences wind velocity. When ridgelines are oriented perpendicular to the airflow, a standing eddy can form on the lee side of the ridge. As gradient winds increase, lee waves and rotors may form and updrafts of up to 100 mi/h may occur (Scorer and Klieforth 1959). Fires may stall on the lee side of ridges due to the retrograde wind direction associated with these conditions.

MICROHABITATS AND FIRE BEHAVIOR

Fire Behavior Terminology—A brief discussion of fire behavior terminology is in order before proceeding with descriptions of plant associations and their fire behavior potentials. Surface fires refer to flaming fronts advancing in surface fuels within 6 ft of, and contiguous to, the ground (Rothermel 1983). Spot fires refer to small fires established by firebrands in advance of the main body of fire. Crown fires are grouped into three classes by Van Wagner (1977):

Passive Crown Fires—Trees torch as individuals, reinforcing the spread rate, but these are not basically different from surface fires.

Active Crown Fires—A solid flaming front develops in the crowns, but the surface and crown phases advance as a linked unit dependent upon each other.

Independent Crown Fires—Fires advance in the crowns independent of surface fire spread.

Characteristics of the microhabitats define fire behavior potentials and effects. As forests approach timberline the general pattern is that they decrease in density and height. As elevation increases, forests eventually break into scattered clumps of trees separated by meadow or park-like openings dominated by shrubs and other low-lying vegetation (Price 1981). Since standard terminology for the plant associations or microhabitats of the alpine timberline is nonexistent, I will rely on nomenclature used by Arno and Hammerly (1984) and Price (1981). Fire behavior characteristics of the microhabitats of the alpine timberline are summarized in table 1.

Upper Subalpine Forests—*Picea engelmannii* and *Pinus albicaulis* are usually codominant in the closed forests that form the lower reaches of the upper subalpine zone (Achuff 1989). *Abies lasiocarpa* is often present. Habitat types representative of this zone include *Pinus albicaulis-Abies lasiocarpa*, and *Pinus albicaulis*. The understory of these forests is strongly dominated by a low-lying shrub, *Vaccinium scoparium*, on many sites in the Northern Rocky Mountains (Weaver and Dale 1974). Forbs such as *Xerophyllum tenax* may also be present.

Table 1—Fire behavior characteristics of the alpine timberline

Microhabitat	Fuel conditions	Surface fire intensity	Crown fire potential[1]	Fire effects
Upper subalpine forest	Heavy loadings possible	High	High	Stand replacement
Open forests	Moderate to low	Low	Low	Favors *Pinus albicaulis*
Krummholz	Moderate	Moderate	High	Return to tundra
Groves	Light	Low	Low	Favors *Larix lyallii*
Ribbon forest	Moderate	Moderate	High	Return to tundra
Cirque basin	Heavy	High	High	Stand replacement
Tundra	Low	Low	Low	Remains as tundra

[1]Under extreme burning conditions and extended drought.

These forests generally occupy sites within or immediately above thermal belts and are subjected to extensive drying conditions. Tightly spaced canopies reduce the amount of precipitation reaching forest floor fuels and vegetation, contributing to increased ignition potential and fire intensity. The intensity of surface fires depends on the amount of downed woody material because the shrub layers are not especially flammable or dense enough to promote high fire intensities. Regeneration of *Abies lasiocarpa* and *Picea engelmannii*, if present, provides ladder fuels and contributes to passive and active crown fire activity. In dense stands, intermingled tree crowns increase the susceptibility of the forests to active and independent crown fire and subsequent stand replacement. Table 2 summarizes the relative fire resistance of alpine timberline conifers in the Northern Rocky Mountains. Following disturbance, regeneration of conifers generally occurs, but growth is slow—often requiring a period of 200 years for conifers to reach diameters of 16 inches (Bigler 1976).

Open Forests—Open stands of *Pinus albicaulis* and *Picea engelmannii* can sometimes be found at the upper reaches of the closed forest zone. Forest floor vegetation consists of low-lying grasses such as *Luzula hitchcockii*; shrubs such as *Vaccinium scoparium*; and forbs such as *Xerophyllum tenax*. Widely spaced tree canopies preclude the development of independent crown fires, but passive crown fire activity can occur with the presence of *Picea engelmannii* or *Abies lasiocarpa* saplings, which transport fires into the upper tree canopy. Surface spread is usually confined to large, downed woody debris, due to the absence of extensive duff and surface fuels. The widely spaced canopy also allows increased penetration of rainfall to the forest floor fuels.

Krummholz—This term describes a vegetation pattern of environmentally dwarfed forms of *Abies lasiocarpa*, *Picea engelmannii*, and *Pinus albicaulis* (Weaver and Dale 1974) that become treelike on favorable sites (Arno 1984). Under dry conditions these dense mats of vegetation can exhibit crown fire behavior in a nontraditional application of the term. Alpine tundra vegetation follows stand replacement fire on these sites and can persist for hundreds of years. Increased snow deposition may occur in unburned krummholz zones on the lee side of burned areas, resulting in additional krummholz mortality, eventually causing a return to alpine tundra vegetation in the unburned krummholz zone.

Ribbon Forest and Snowglade—On gentle slopes or plateaus the forest tends to occur in elongated strips aligned perpendicular to the normal winter wind direction. Ribbons are usually 10 to 20 m across and may be several hundred meters long. Ribbons are commonly composed of *Abies lasiocarpa* and *Picea engelmannii* (Billings 1969). *Larix lyallii* and *Pinus albicaulis* may also occur in the ribbons (Arno and Habeck 1972). Moist bands of subalpine meadow vegetation, large tussock-forming grasses and sedges, occupy intervening strips 25 to 75 m across and are the result of snow deposition on the lee sides of the forested ribbons. Fire activity is usually quite localized because of the intervening meadow vegetation (Billings 1969). Both crown and surface fires can occur in the ribbon forest. Low-intensity surface fires may modify the understory vegetation and have little effect on the coniferous ribbons; while crown fires have long-term effects. Succession back to the ribbon forest pattern usually requires several hundred years (Billings 1969).

Groves—Generally associated with *Larix lyallii* in the Northern Rocky Mountains, these small stands of trees usually occur on moderately cool exposures above the tree limit for other species of conifers (Arno 1972). Groves of *Larix lyallii* may also occupy bedrock and coarse talus sand within or adjacent to talus slopes (Arno 1972). Under extreme conditions fires can burn woody debris and depositions of litter occurring on talus slopes, but will not generally cause mortality in the groves. Fire-scarified seedbeds adjacent to the talus slopes can seed in rapidly with *Larix lyallii* seedlings (Arno 1972).

Tundra—This plant association grows above the climatic timberline and is characteristically dominated by low-growing (20 cm or less), perennial, herbaceous, and shrubby vascular plants, and extensive mats of cryptograms (Thilenius 1975). Fire does not appear to be influential in the tundra association (Thilenius 1975). Where tundra has extended below timberline as the result of past fires, larger downed woody debris may remain on these sites and serve as the mechanism of fire spread.

Table 2—Fire resistance of alpine timberline conifers (adapted from Flint 1925)

Species	Fire resistance	Bark	Stand habit	Branch habit
Abies lasiocarpa	Very low	Very thin	Moderate	Low and dense
Pinus albicaulis	Moderate	Thin	Open	High and open
Larix lyallii	Moderate	Thin	Open	Open
Picea engelmannii	Low	Thin	Dense	Low and dense

Cornice Lines—These snow deposition zones form along ridgelines and are composed of moist subalpine meadow vegetation, large tussock-forming grasses, and sedges. Surface firespread through these treeless strips is limited. This feature may prevent firespread across ridgelines under moderate burning conditions. The presence of a cornice line contributed to the confinement of the Charlotte Peak fire to the Holbrook drainage under severe burning conditions in 1985 in the Bob Marshall Wilderness (Lasko 1986).

Cirque Basins—Moist conditions and topographic features shelter these sites from all but the most severe episodes of external fire. *Pinus albicaulis* can be present, but the dominant coniferous species is *Picea engelmannii*. Shrubs such as *Menziesia ferruginea* commonly inhabit the forest floor and retard the spread of surface fire under most condtions. Under the severest of burning conditions, at the latter stages of stand succession when large amounts of downed woody debris are present, stand replacement crown fires can occur. Site characteristics generally allow the establishment of coniferous regeneration within 10 years of major disturbance. Two hundred years were required for trees to reach 18 inches in diameter in cirque basin stands above 5,000 ft elevation in northwestern Montana (Bigler 1976).

SUMMARY

Fire management programs create subtle yet long-lasting alterations in the alpine timberline. Fires less than 10 acres in size can alter vegetation patterns for hundreds of years. Continued elimination of fire from this zone delays its inevitable occurrence, increases fuel loadings, and ensures the severity of future fires. The desire of the public for a risk-free environment and the maintenance of existing landscapes, add to the complexity of the situation. A clear understanding of the role of fire is prerequisite to correct management of the timberline resource. Limited experience with the application of fire in the alpine timberline requires us to proceed with caution.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from anonymous)—What do you see as the role of human-induced fires in the management of whitebark pine in wilderness systems, when considering mountain pine beetle and blister rust?

A.—The interactions between fire, mountain pine beetle, and white pine are ecosystem processes that the Wilderness Act was established to perpetuate with as little influence by humans as possible. The introduction (by humans) of nonnative organisms will alter or shift affected ecosystems. In the instance of blister rust the best we can do is probably document the effects on the ecosystem.

SILVICULTURAL MANAGEMENT ALTERNATIVES FOR WHITEBARK PINE

Douglas E. Eggers

ABSTRACT

Whitebark pine (Pinus albicaulis) *has received little management emphasis except in the past 10 years. Silvicultural treatment of whitebark pine is starting to draw increased interest as attention is focused on the species and its potential management. The objective of this paper is to summarize what is currently known about the silvicultural management of the species. There has been little written concerning silvicultural treatment in whitebark pine stands; however, there are some inferences that can be drawn by examining specific examples. These examples will be used to demonstrate that information does exist and that these existing data will probably need to be used to guide management while additional data are gathered and understanding is gained.*

SILVICULTURAL OBJECTIVES

The most important factor to keep in mind (and the one so often neglected) when examining silvicultural management alternatives for whitebark pine (*Pinus albicaulis*) is the need to identify clear, accomplishable, land management objectives. Daniel and others (1979) described the role of silviculture in forest and wildland management. Formulating silvicultural strategies requires the recognition of biological, managerial, and economic considerations. For example, objectives for recreation, water production, wildlife, or wood may require forests with different structures. Translating those objectives into specific kinds of stand structures and composition then becomes a matter of silvicultural application. This silvicultural application involves a basic understanding of principles that will in turn translate into recommended practices. This paper will not address different land management objectives other than showing how they may affect treatments. The assumption is made that the perpetuation of the whitebark pine component is desired.

In translating land management objectives into tangible, specific activities, it is important to define the subject using accepted forestry terminology. The terms used here are taken primarily from the Society of American Foresters' publication, "Terminology of Forest Science, Technology, Practice and Products" (Ford-Robertson 1971).

The first definition, silviculture, is fundamental to the rest that will be presented in this paper. Silviculture is defined as follows:

1. Generally, the science and art of cultivating (growing and tending) forest crops, based on a knowledge of silvics.
2. More particularly, the theory and practice of controlling the establishment, composition, constitution, and growth of forests (Ford-Robertson 1971).

The definition can be refined further to understand that silvics is: "The study of the life history and general characteristics of forest trees and stands, with the particular reference to locality factors, as a basis for the practice of silviculture" (Ford-Robertson 1971). Examination of the "theory and practice of controlling the establishment, composition, constitution, and growth" of whitebark pine based on what is known about its life history and general characteristics, using some specific references to locality factors, will be the focus of this paper. The specific examples given will utilize what is known of current stand structure and knowledge of stand history as well as ecological information to project the treatments necessary to produce the desired future conditions.

CONTROLLING ESTABLISHMENT

Controlling establishment involves "The process of developing a crop to the stage at which the young trees may be considered established; i.e., safe from normal adverse influences—e.g., frost, drought, weeds or browsing—and no longer in need of special protection or special tending, but only routine cleaning, thinning, and pruning" (Ford-Robertson 1971).

The process of developing a crop of whitebark pine to the stage that it is considered established or free to grow starts with regeneration. Daniel and others (1979) distinguished between silvicultural reproduction (regeneration) methods and silvicultural systems: a regeneration method describes the manner of cutting to ensure regeneration and a silvicultural system describes additionally the process for treating the resulting stand after establishment. Attention will be focused on regeneration rather than on silvicultural systems. The regeneration methods that could be used in whitebark pine stands, according to Arno and Hoff (1989), would be either even-aged or uneven-aged depending on site factors and management objectives. Even-aged regeneration methods are clearcutting,

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seed tree, and shelterwood. Uneven-aged regeneration methods are single tree and group selection. These various methods form a continuum, as described by Daniel and others (1979); the amount of site exposure that results ranges from the least, with single tree selection, to the greatest, with clearcutting.

The silvical characteristics of whitebark pine including irregular large cone crops, uncertain seed dissemination, and low seed germination, will narrow the range of silvicultural options that are feasible for any particular site.

There has been little management activity in northwestern Wyoming that has focused directly on whitebark pine. Only in recent years has there been much attention given to whitebark pine, therefore, there is not the amount or detail of data available that there is for some other species. However, observations have been made that should be valuable in evaluating the appropriateness of prescribing various regeneration methods. The types of data, such as timber inventory data, that exist for the Bridger-Teton National Forest, also exist for most other National Forests.

Arno and Hoff (1989) noted that whitebark pine often regenerates following wildfire and after clearcutting (with or without site preparation) on southern exposures or ridgetops. They also observed that to regenerate whitebark pine on moist sites, appreciable stand opening and localized site preparation would probably be necessary. Arno and Hoff (1989) found that whitebark pine can be regenerated artificially by using seedlings or seeds in mineral soil or at the soil-litter interface. Eggers (1986) has noted various artificial regeneration methods that could be utilized.

The author has made observations on a study site located in the Union Pass area of the Bridger-Teton National Forest that was set up in 1971 to evaluate several methods of harvesting mature lodgepole pine (*Pinus contorta* Dougl. ex Loud.) and to compare postharvest treatments (Benson 1982). These observations have shown that whitebark pine seedlings are becoming established on this site. The greatest number of seedlings is located in the areas that received the treatment of clearcut, tractor pile, burn, and plant. This stand, prior to harvest, had over 1,500 stems/acre of whitebark pine under 5.0 inches d.b.h. These seedlings, which became established under the closed canopy of the predominately lodgepole pine stand over its 160-year life span, were of poor quality and arranged in a clumpy pattern (Benson 1982). The evidence would indicate that if there is whitebark pine in surrounding stands, within 10 to 15 years there will be some stocking of whitebark pine in clearcuts.

At this relatively moist, higher elevation (9,200 ft) where strong winds are experienced during the winter, it is probable that some seed dispersal takes place from seeds being blown along on crusted snow. There could be some dispersal by rodents or birds, however, the pattern of occurrence corresponds to that of seedlings of other species started from wind-borne seed. There were more seedlings observed on the north and northeast sides of the planted lodgepole pine, which would seem to indicate that some degree of shading may benefit establishment. The whitebark pine seedlings found in this area are single and not clustered as they would be if a whole cone disintegrated on the ground and the seeds germinated.

One of the factors that has contributed to the seedling establishment of all species in this area is the wet seasons that occurred during the mid-1980's. It is also interesting to note that observations made in late 1988, after one of the driest years on record, confirmed that a number of first- and second-year seedlings were still alive. This would indicate that after germination, vigorous rooting takes place, thereby aiding survival.

There have been questions raised on the value of releasing understory whitebark pine. My observations, made primarily in mixed species stands in which whitebark pine is a component, of the growth response of residual seedlings and saplings of whitebark pine after release have indicated that residual seedlings and saplings have responded little to release. The observations were made in clearcuts and in stands with various levels of partial cutting (some regeneration harvests and some intermediate harvest). This is an area that needs additional data to determine more of the specific characteristics of the residuals such as age at release and average growth prior to release.

The inference that can be drawn from these observations is that whitebark pine establishment is enhanced by bare mineral soil and an abundance of moisture. Germination is one of the most critical factors known at this time. Answers to the whys of poor germination are currently unknown. Pitel and others (1980) indicated that there appears to be a relationship between the completeness of development of the embryo and the condition of the seed coat that affects germination. The factors at work here are important, but personal observation has shown that more seedlings are visually evident after a wet season, particularly a wet spring, than any other time. More moisture is permeating the seed coat, thereby aiding germination, whatever the mechanism is for breaking down seed dormancy.

There are silvical characteristics important to establishment that can be controlled with some degree of predictability. Seed production, is one such characteristic. Flowering and fruiting is an integral part of seed production and can be influenced by the application of spacing control to produce trees with a higher proportion of crowns that are fully exposed to light (Daniel and others 1979). Techniques used in seed production areas such as thinning, fertilization (after foliar analysis), and protection from insects and other seed destroying agents could also be used.

Regeneration methods that recognize the basic silvical needs of the species will be the most successful. Additional examples are described by Arno and Hoff (1989), such as a rooting habit that develops a deep spreading system. The root system is well-anchored in the rocky substrate and is seldom disturbed despite the tree's large, exposed crown and the violent winds to which it is subjected. They also indicated that while whitebark pine had previously been reported as very intolerant, more recent observations show that it would be more accurate to classify it as intermediate in tolerance to shade.

Whatever regeneration method is chosen, the retention of healthy, windfirm seed trees with good phenotypic

characteristics will aid in natural regeneration. It is important to realize that regeneration through natural regeneration alone will probably mean long regeneration periods. These regeneration periods may be decades, in comparison to a few years for such associated species as Engelmann spruce or lodgepole pine. The characteristic that whitebark pine is intermediate in tolerance would indicate that there will be some seedlings that become established.

Using the Bridger-Teton National Forest as an example, in the short term, if the whitebark pine component is to be increased or its range is to be extended, artificial regeneration will be necessary. If this option is chosen, it will be very expensive to carry out on an operational basis. It is not an easy solution, as described by Eggers (1986), but one that could be carried out if management emphasis and budget were committed to it.

CONTROLLING COMPOSITION

Composition is defined by the Society of American Foresters (Ford-Robertson 1971) as the "species composition of a forest crop or stand, the representation of tree species in it. This is expressed quantitatively as percent by volume or basal area of each species; percent by number only at the seedling stage."

The species composition that is desirable may be dependent on the land management objectives, but what is possible will be dependent on inherent characteristics such as site quality, habitat type capabilities, and presence or absence of pest agents. Whitebark pine, Society of American Foresters Cover Type 208, (Eyre 1980) is used to designate pure stands or mixed stands in which the species comprises a plurality of stocking. It is necessary to know the existing vegetation to formulate a better prescription for what is desired. For example, in the over 50 forest habitat types identified in the eastern Idaho-western Wyoming area, whitebark pine was found in 36. On the Bridger-Teton National Forest, whitebark pine occurs with lodgepole pine, limber pine (*Pinus flexilis* James), Engelmann spruce (*Picea engelmannii* Parry ex Engelm.), subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.), Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco), and aspen (*Populus* spp.). The single-stemmed growth form is most commonly associated with a plurality of lodgepole pine. The multi-stemmed growth form is more commonly found with a plurality of whitebark pine at the extremes of environmental conditions. Common shrub and herbaceous associates are listed in "Forest Habitat Types of Eastern Idaho-Western Wyoming" (Steele and others 1983). This publication lists the percentage canopy coverage by species and the constancy or the percentage of stands in a habitat type that contain a given species.

Controlling the species composition begins with establishment, through the favoring of trees left for seed or artificial reforestation. The time between establishment and the next regeneration period can be used to perform a whole range of stand manipulations, generally termed intermediate treatments, to control the species composition. Cleaning, weeding, liberation, and improvement cuttings could be used at various stages of stand growth, singly or in combination, to achieve the land management objectives.

CONTROLLING CONSTITUTION

Constitution is the "structure, of a forest crop or stand, the distribution and representation of age and/or size classes" (Ford-Robertson 1971).

Land management objectives will guide the controlling of distribution of age and size classes of whitebark pine and specific stand structures: the relative proportion of overmature (declining in vigor, health, or soundness), mature (full development of height and seed production), saplings, and seedlings. Success requires an understanding of stand dynamics including succession, competition, and tolerance. This can be aided by the identification of habitat types as described in the previous section. The various pathways of succession are affected by the starting point. The progression toward climax vegetation will continue without treatment, but the character of the stand can be changed through treatment. The silviculturist can control the structure by applying various treatments including harvesting, site preparation, controlling species composition, and thinning. These choices will affect the ways individual trees and species will respond. These choices may range from broad to narrow in the short term depending on the character of the existing stands.

An illustration from the Bridger-Teton National Forest timber inventory information will help to put this into perspective. Examining the timber inventory plot data has given a profile of the existing condition of the whitebark pine resource:

Characteristic	Average for whitebark pine
d.b.h.	14.9 inches
height	51 feet
d.b.h. age	157 years
past 10 yrs. radial growth	0.25 inches (range 0.1 to 0.9)
best 10 yrs. radial growth	0.8 inches (range 0.25 to 2.25)
age of best growth	20 years
elevation	9,000 feet

These facts should help when writing prescriptions that will be able to be implemented. What does an analysis of these data show? It shows that for the Bridger-Teton National Forest, the whitebark pine is a mature/overmature resource that is currently growing slowly, but at younger ages is capable of growing as well as its associates.

CONTROLLING GROWTH

Growth is described as: "increment, accretion. The increase in girth, diameter, basal area, height, volume, quality or value of individual trees or crops" (Ford-Robertson 1971).

The definition of growth covers the whole range from individual trees to entire forest. Land management objectives should indicate the relative importance of various growth factors. This could mean quality or value in terms of such characteristics as multi-stemmed growth habit, foliar biomass, or consistently large seed crops.

There are basic standards that should be reviewed to be able to set realistic growth expectations. A number of these have been described in earlier sections. There are

givens. For example, the height that a tree can reach at a certain age on a particular site is largely limited by soil and climatic factors. Different species respond differently to differing site quality. It is important to recognize that whitebark pine grows over a range of climatic conditions but is characterized by Arno and Hoff (1989) as growing in cold, windy, snowy, and generally moist conditions. They indicated that in moist mountain ranges, whitebark pine is most abundant on warm, dry exposures and in semiarid ranges it becomes prevalent on cool exposures and moist sites. The mean annual precipitation for most stands where whitebark pine is common is between 24 and 72 inches with about two thirds of the precipitation coming in the form of snow and sleet.

In considering environmental factors affecting growth of whitebark pine stands, two of the most important are insects and disease. The most damaging insect pest of whitebark pine is the mountain pine beetle (*Dendroctonus ponderosae* Hopkins). There has been a significant amount of mortality in mature stands throughout the northern Rocky Mountain area Arno and Hoff (1989). This insect may kill individual trees even at higher elevations but most whitebark pine tree killing in northwestern Wyoming occurs when beetle populations build up in lodgepole pine stands at lower elevations. Management in lower elevation stands may need to increase to lessen the impact on higher elevation stands. Mountain pine beetle has caused severe damage to some whitebark pine stands. The principal disease that causes damage to whitebark pine is white pine blister rust (*Cronartium ribicola*); it usually results in death in sapling and pole-sized trees and top killing in mature trees.

We also need to recognize that basic tree physiological principles are at work even though we may not know or recognize them all for whitebark pine. Examples are: the major reasons why understory may not respond after release are that poor root systems can't use the increased nutrients, low live crown ratio won't allow adequate food production, or advanced age decreases ability to respond.

In the area of growth, as in establishment, composition, and constitution, there are some specific examples from data collected in unmanaged stands that can be used to illustrate what is known. From these examples inferences can be drawn on the expectations from stand manipulations. The major growth factors that can be affected by management activities are: controlling composition and manipulating density.

The following examples from the Bridger-Teton National Forest will help to demonstrate:

The best whitebark pine height growth on the Bridger-Teton National Forest (as evidenced by the greatest number of plots with trees over 70 ft in height) was recorded at elevations between 8,300 and 9,100 ft.

The most prevalent habitat type for these plots was *Abies lasiocarpa / Vaccinium scoparium-Vaccinium scoparium* phase. The *Abies lasiocarpa* Series is the most prevalent on the Forest and *Vaccinium scoparium* is the most prevalent habitat type in the *Abies lasiocarpa* Series. The yield capability for this habitat type is quite broad, ranging from 20 to 90 cubic ft per acre per year (Steele 1982). The inventory data showed that on the above habitat types we can expect a tree that is 17 to 20 inches d.b.h. and over 70 ft tall to be between 150 and 175 years old. Trees that are over 30 inches d.b.h. and over 90 ft tall are usually at least 220 years old. One of the larger specimens recorded on the inventory plots was 38.1 inches d.b.h., 111 ft tall and 281 years old. We can also infer from the inventory that the growth pattern after establishment could follow the progression shown in table 1.

It will help lend perspective to the observations by recognizing that in terms of relative productivity, the Bridger-Teton National Forest has the highest overall productivity of any National Forest in the Intermountain Region of the Forest Service. The Bridger-Teton's average productivity potential is 63 ft^3/acre/yr, (USDA Forest Service 1980) which compares to an average of 64 ft^3/acre/yr for the Rocky Mountain area as a whole (USDA Forest Service 1982).

Table 1—Growth examples at various ages from Bridger-Teton National Forest inventory

Age	D.b.h.	Height
Years	*Inches*	*Feet*
25	5.3	21
40	10.8	41
70	12.6	67
100	13.7	71

CONCLUSIONS AND RECOMMENDATIONS

It would seem that whitebark pine is neither the mystical nor mysterious species that some have made it out to be, but one for which a broader base of knowledge is needed. The attention focused recently on whitebark pine due to its relationship with grizzly bear habitat has helped to add to the knowledge base. We need to use the information, such as timber inventory plot information, that is currently available until more site-specific information for particular stands is collected. By observing what has happened in stands that have been entered, a silviculturist should be able to determine appropriate ways to manipulate individual stands to meet land management objectives. These land management objectives need to be clearly stated in quantifiable terms. We can then work toward developing the types of stands that we desire, while recognizing that it will take a considerable amount of time to get them.

Future research and information needs:

1. Continue to refine nursery propagation techniques,
2. Continue the genetic work to determine variability in whitebark pine,
3. Delineate and define objectives for those stands that need management prescriptions, and gather the site data needed.

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RECLAMATION PRACTICES IN HIGH-MOUNTAIN ECOSYSTEMS

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ABSTRACT

Mineral exploration, mining, road construction, and recreation have resulted in severe disturbances to many subalpine and alpine ecosystems throughout the mountainous West. Revegetation research has revealed several promising techniques that may lead to the rehabilitation of these disturbances. The selection and use of adapted native plant species representative of different seral stages are needed to provide optimum species and structural diversity in revegetated communities. Amendments such as fertilizer, organic matter, and surface mulching that ameliorate limiting adaphic and microclimatic conditions are essential.

INTRODUCTION

High-elevation mountainous regions of the western United States support vitally important ecosystems. They are the primary watersheds for agricultural, industrial, and metropolitan development as snow accumulation and water storage in these areas provide the main sources of summer runoff for western streams and rivers. The more gentle slopes and rolling plateaus of mountain regions also provide summer range for both livestock and wildlife, and these unique ecosystems offer stunning panoramas and remote wilderness solitude for recreationists. However, with the advent of modern technology many areas are being disturbed at an accelerated rate by human activities such as recreation, road construction, mineral exploration, mining, and other endeavors.

The impacts of disturbance on high-elevation lands threaten their important watershed, wildlife habitat, grazing, and recreational values. Revegetation of these disturbances is essential to minimize the consequences of erosion and loss of water quality, and to reestablish stable native ecosystems. However, conventional techniques of revegetation developed for more moderate climatic zones at lower elevations have largely been unsuccessful for disturbed high-mountain ecosystems. The rigorous climate at high elevations, coupled with the impacts of disturbance, dictate the use of techniques that have been designed for the unique conditions of high-elevation lifezones. Short, cool growing seasons, strong winds, frequent frosts, and a limited pool of adapted plant species severely complicate revegetation efforts. These constraints are compounded by the effects of disturbance that often result in spoil material that is acidic, low in essential plant nutrients, or contains toxic concentrations of heavy metals or other unsuitable constituents. Erosion, acid-water runoff, and sedimentation frequently result in the destruction of off-site plant communities, streams, and aquatic habitats, and the general deterioration of water quality.

In 1972 the Intermountain Research Station initiated an integrated research effort to develop revegetation techniques for high-elevation disturbances. Also, considerable interest was fostered in high-elevation revegetation problems throughout the West with the establishment of the High-Altitude Revegetation (HAR) Committee. Early attempts to revegetate disturbances at high elevations were frustrated by a lack of knowledge about the complexities of high-elevation environments and the effects of disturbances. However, during the last 15 to 20 years numerous promising techniques and approaches have been developed for the revegetation of these areas. The purpose of this paper is to summarize the nature of high-elevation environments, the effects of disturbance on them, and the more successful revegetation techniques available.

FACTORS LIMITING REVEGETATION

Climatic conditions of high-elevation regions are often limiting to successful revegetation of disturbances. Generally, high-elevation environments have low heat budgets that result in short, cool growing seasons (Billings 1974). Typical high-elevation growing seasons range from 45 to 90 days with average summer temperatures near 10 °C (Billings and Mooney 1968). Growing season temperatures frequently fall below 0 °C, and frost occurs throughout the growing season in many areas. Needle ice can uproot seedlings and contribute to surface soil erosion on disturbed sites throughout the growing season where soil water status is maintained at or near saturation (Brink and others 1967). At high elevations in the western United States precipitation occurs mainly as winter snow, but soil water availability is highly variable with

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season, location, and topography. For example, snow fields commonly accumulate on the lee sides of ridges while ridgelines may remain nearly snow free due to redistribution by wind. High winds are common in subalpine and alpine ecosystems, and can cause significant soil erosion and be physically and physiologically detrimental to plants. Also, wind coupled with high solar radiation flux densities in mountain life-zones can promote extremely high rates of evaporation and transpiration.

The type of disturbance imposes various limitations on successful revegetation. Severe disturbances result in the removal of surface soil horizons and expose the underlying geological materials. Less severe disturbances leave the surface soil in place but may result in the mixing of the surface and subsurface soil horizons (Chambers and others 1988). Natural causes of severe disturbances include geomorphological processes such as landslides or avalanches; human causes include such activities as road building and mining. Less severe disturbances result from causes such as freeze-thaw cycles (Johnson and Billings 1962), small-mammal burrowing and tunneling (Thorn 1982), and some human recreational activities. The two types of disturbances result in significantly different revegetation environments. Severe disturbances that remove surface organic horizons and leave mineral soils in place are often characterized by lower water and nutrient holding capacities. Disturbance in general can result in the loss of finer soil particles due to wind erosion.

Severe disturbances at high elevations can expose pyrtic materials that initiate a cycle of sulphide oxidation near the soil surface (Johnston and Brown 1979). This can result in low soil pH and increased availability of potentially toxic metals such as copper, iron, and aluminum. Plant establishment and growth, and thus, natural successional processes, can be severely limited. Runoff from such areas frequently causes mortality to offsite plant communities and seriously degrades water quality and aquatic ecosystems downslope.

A major limitation to successful high-elevation revegetation is knowledge about the selection and use of adapted plant species. The total flora of high-elevation ecosystems is relatively small compared with more moderate low-elevation life-zones, and the pool of adapted species suitable for revegetation is limited. Introduced plant species commonly used for revegetation in lower elevation areas are frequently unadapted and unsuccessful when used for revegetation of high-elevation disturbances. Brown and Johnston (1979, 1980) found that such introduced species as smooth brome (*Bromus inermis*) and intermediate wheatgrass (*Agropyron intermedium*) were no longer present 4 years after planting on a subalpine site that had been mined in southwestern Montana. However, native adapted species from the area such as tufted hairgrass (*Deschampsia cespitosa*) and alpine bluegrass (*Poa alpina*) increased in density, cover, and biomass production over the same period. The most important criteria used in selecting adapted species for revegetation, including observations of natural succession on disturbed areas, are discussed by Chambers and others (1984, 1988).

SELECTION OF ADAPTED PLANT SPECIES

Selecting plant species for revegetation that are suited to the limiting environmental factors characteristic of a disturbance is one of the most important aspects of successful reclamation. Adapted species are those capable of long-term survival and reproduction. One of the most promising methods of identifying adapted species for revegetation of high-elevation disturbances is to examine natural successional processes on local old disturbances such as road cuts and fills and gravel pits (Brown and Johnston 1980; Chambers and others 1984, 1988). Unfortunately, most native high-elevation plant species suited for revegetation are not commercially available and must be hand-collected. Collection of seed tends to be expensive, but use of locally adapted populations greatly enhances the chances for successful revegetation.

Species Selection

Research results suggest that reclamation success of high-elevation disturbances may be improved when mixtures of species are planted that represent different life histories and physiological traits. Typically, grasses are the most widely used group of plants in revegetation, yet heavily fertilized swards of high-nutrient adapted grasses often tend to form closed stands that exclude or inhibit the invasion of other species (Brown and others 1984). Research on plant succession on high-elevation disturbances suggests that inclusion of different lifeforms in seeding and planting mixtures, together with appropriate amendments, may increase species and structural diversity of revegetation communities and enhance rates of successional development (Chambers and others 1988). In addition, use of seed mixtures consisting of species with many different physiological and ecological characteristics improves the chances of stand survival in the event of catastrophic events such as insect infestations, disease, or drought (Brown and Johnston 1980).

In alpine environments many plant species adapted for revegetation of disturbances can be classified according to their frequency of occurrence in different successional stages (Chambers and others 1984, 1988). Initial colonizers of disturbed sites often exhibit broad ecological amplitudes, and are usually widely distributed in geographic area. At low elevations early colonizers tend to include a large complement of annual "weeds"; at higher elevations more desirable perennial species predominate. Early colonizers often have large and consistent seed production capabilities, effective seed dispersal mechanisms, high seed germination percentages, and high rates of growth and development. They may also be able to tolerate high concentrations of heavy metals, low pH, and other adverse disturbance conditions.

Late-seral species often have slower growth rates, lower seed production, and lower rates of seed dispersal than early seral species (Chambers and others 1988). For example, frequent colonizers such as tufted hairgrass typically produce large quantities of small-sized seeds with high viability and germination, have high seed

longevity, high seed dispersal capability, high plant growth rates, and low root:plant biomass ratios (Chambers and others 1988). In contrast, species typical of late-seral communities such as alpine avens (*Geum rossii*), an alpine forb, produce small quantities of larger sized seeds with relatively short seed longevity, low seed dispersal capability, low growth rates, and high root:plant biomass ratio (Chambers and others 1988). Also, tufted hairgrass tends to have shallower, less extensive root systems and higher nutrient requirements than alpine avens (Chambers and others 1987c). Species adapted to low-nutrient sites, such as alpine avens, can ensure long-term stability on disturbances, but lower rates of production are to be expected (Chambers and others 1988). Listed below are native alpine and subalpine species that have been established successfully on disturbed sites from seeds (*), together with others that have favorable characteristics for revegetation (Brown and others 1978, 1988; Chambers 1987; Chambers and others 1984, 1988):

Grasses and Grasslike Plants—

**Agropyron trachycaulum* (slender wheatgrass)
**A. scribneri* (Scribner wheatgrass)
**Carex paysonis* (Payson sedge)
**Deschampsia cespitosa* (tufted hairgrass)
**Phleum alpinum* (alpine timothy)
**Poa alpina* (alpine bluegrass)
P. epilis (skyline bluegrass)
P. rupicola (timberline bluegrass)
**Trisetum spicatum* (spike trisetum)

Forbs—

**Achillea millifolium* (western yarrow)
Agoseris glauca (pale agoseris)
Arenaria obtusiloba (alpine sandwort)
Artemisia campestris (wormwood)
**A. scopulorum* (alpine sagebrush)
Cerastium arvense (mouse-ear chickweed)
C. beeringianum (alpine chickweed)
**Geum rossii* (alpine avens)
Lupinus argenteus (lupine)
**Potentilla diversifolia* (varileaf cinquefoil)
Senecio fremontii (Fremont's groundsel)
**Sibbaldia procumbens* (sibbaldia)
Smelowskia calycina (smelowskia)
Solidago multiradiata (low goldenrod)
Trifolium dasyphyllum (whiproot clover)
T. parryi (Parry clover)

Many of the species listed have broad ecological amplitudes and occur as frequent colonizers on alpine disturbances. Also, many have high reproductive rates and easily collectible seeds.

Seed Collection

Seed collection of adapted native species requires a knowledge of the phenology of plant development and the complex interactions with environment. Seed maturity and production are highly variable from year to year, and collection must be opportunistic to take advantage of good seed production years for different species. Several years may be required to collect sufficient seed of all species desired for a given revegetation project. Usually, seeds mature on the plant in the late summer or fall, and should be collected just prior to natural dispersal. The seeds are normally stored in dry, porous containers such as paper or cloth bags, and kept in a cool, dry environment maintained near 0 °C (Chambers and others 1987a). However, there is some evidence that seed longevity of high-elevation species is improved if seeds are stored at −18 °C at low moisture content (Billings and Mooney 1968).

Seed Mixtures and Planting Concerns

Seeding rates based on the number of viable seeds per unit area for each species used, instead of the more typical method of weight per unit area, allow rates to be determined on an individual species seed viability basis. This ensures that potential competition among species will be uniform over the area, provides optimum opportunity for survival of seedlings, and permits success or failure of each species in the mixture to be correctly assessed. The amount of seed applied for each species in a mixture may need to be adjusted for different seed lots collected from different locations and times because seed viability varies widely from year to year (Chambers in press).

Knowledge of seed germination requirements of species is essential to determine seeding methods and other revegetation techniques. Many species have small-sized seeds that cannot emerge from the soil if planted too deeply; species with larger sized seeds may require deep planting to avoid desiccation during dormancy and seedling development. Also, some species must be planted at or near the soil surface because of a requirement for light during germination (Chambers and others 1987b; Haggas and others 1987). Chambers and others (1987b) found that many alpine forbs require light for germination, but grasses have less specific requirements. Also, they found that wet cold stratification during the winter following fall seeding results in fewer days for germination and, consequently, an increased likelihood of seedling establishment the following spring.

Nutrient Requirements and Growth

Use of fertilizer is a common practice in revegetation, yet little is known about the growth responses to specific nutrient levels or nutrient requirements of native high-elevation plant species (Brown and Johnston 1979; Chambers and others 1988). Although highly site specific, nitrogen (N) and phosphorus (P) are usually the most limiting nutrients on disturbances, but individual species responses to these nutrients vary widely. The availability of these and other nutrients and the nutrient retention capacity of a soil are often determined by the severity of the disturbance (Tilman 1986). Chambers and others (1988) found that tufted hairgrass, a frequent early colonizer on alpine disturbances, responded more to N inputs, and that the typical late-successional species, alpine avens, respond more to P. They also showed that tufted hairgrass had greater rates of growth at all levels of N and P than alpine avens. This suggests that tufted hairgrass may have competitive superiority over alpine avens on disturbances and over broad ranges of available N and P.

However, factors other than fertility and growth rate may affect the interactions among species in a revegetation mixture. Low growth rates and high root:shoot ratios are important attributes of species adapted to low-nutrient environments. Including species in a seed mixture that are low-nutrient and low-growth-rate adapted together with those that are high-nutrient and high-growth-rate adapted can help ensure long-term stability on nonintensively managed reclaimed disturbances. It may be necessary to use moderate seeding and fertilizer rates and to seed low-growth-rate species in equal amounts with high-growth-rate species in such mixtures.

RECLAMATION METHODS

The immediate goal of revegetation is to provide protection and surface stability on disturbed sites, but esthetics and long-term site stability are also important concerns. The general principles of revegetation applicable to disturbances in all life-zones, such as shaping and contouring, fertilizing, seeding and planting, and mulching apply to high-elevation disturbances. However, under the severe environmental conditions unique to high elevations in the mountainous West, the more subtle aspects of timing, species selection, and microenvironmental concerns often determine the difference between success and failure in revegetation. A primary objective of revegetation is to ameliorate soil and microclimatic conditions that are limiting to the physiological tolerances of otherwise adapted plant species on that site. For remote area disturbances that will be managed at low intensity levels following revegetation, proper methods should lead to site conditions that promote natural succession by enhancing invasion and colonization of different microorganisms, plant lifeforms, and animal species. Ultimately, a plant community should be established that is commensurate with ecosystem dynamics of that area.

Contouring and Shaping

Mine spoil piles, old roadbeds, and other severe disturbance areas should be reshaped to conform to the original contour of the land as nearly as possible (Brown and Johnston 1979). Reshaping should minimize slope angles, sharp ridgelines, and undrained depressions that lead to wind-scour, excessive erosion or overland flow, and water accumulation. Contouring should be designed to promote optimum environmental conditions for plant establishment and growth. Spoil or soil materials containing toxic concentrations of heavy metals and acid-bearing wastes should be buried under the best growing medium available in areas where subsurface drainage is not likely to cause contamination or loss of water quality. Topsoil should be stored and replaced before reclamation wherever possible. Contouring and shaping work should be completed well in advance of planned revegetation to permit settling to occur before seeding and planting. Ripping compacted spoil material may be necessary to promote root aeration and growth, and to facilitate water and nutrient absorption.

Season and Timing of Revegetation

High-elevation disturbances should be revegetated in the fall. Timing of revegetation has been found to be extremely important to successful plant establishment (Brown and Johnston 1980; Chambers 1987). Transplant stock should be hardened to low fall temperatures and should be in a dormant condition during planting. Seed, transplants, and soil amendments should be applied as late in the growing season as possible so that cold temperatures prevent germination and growth. Severe frost damage to young seedlings and transplanted stock may result if planting is too early. Fall revegetation ensures that seeds and amendments will be in place when conditions are ideal for germination the following spring as snowmelt occurs. Fall seeding and planting can usually be accomplished when conditions are relatively dry and when the soil or spoil can be worked most easily.

Spring or summer revegetation can be detrimental to successful plant establishment on high-elevation disturbances. Most high-elevation areas remain inaccessible in the spring until large snowdrifts melt. By the time access and site conditions are suitable, the optimum conditions for seed germination and seedling development may be passed.

Nutrients and Other Soil Amendments

A complete soil analysis should be performed well before seeding and planting so that low levels of available plant nutrients and potentially limiting physical or chemical soil properties can be identified (Chambers and others 1987a; Jurinak 1982). Mine spoils and other disturbed sites are often deficient in required nutrients for higher plants, and may have low pH and toxic concentrations of heavy metals that limit plant establishment. Amounts and ratios of fertilizers should be determined from levels of nutrients already present in the soil, the nutrient retention and cycling capacity of the soil, and the particular requirements of plant species to be seeded. In general, soils with high percentages of organic matter and fine textures have greater nutrient retention capacities than coarse mineral soils low in organic matter. Consequently, one-time applications of fertilizer may have more long-term benefits in fine-textured soils with greater amounts of organic matter. To substantially increase levels of available plant nutrients in mineral soils, organic matter additions may be necessary. Nutrient levels in the soil should be balanced for both high- and low-nutrient-adapted species. It is important to add a proportion of low-nutrient-adapted species to the seed mixture for low organic matter mineral soils to ensure long-term site productivity.

Fertilizer should be distributed uniformly over the site in the proper proportions to achieve the desired ratio of N-P-K and other needed nutrients. Commercially available hand-operated distributors perform acceptably with granular fertilizers (Brown and Johnston 1979, 1980). Normally, rates of application on high-elevation disturbances range from about 50 to 110 kg of N per ha, but

actual rates vary with specific sites and objectives. The site should be harrowed, raked, or rototilled to incorporate the fertilizer into the upper 15 to 30 cm of soil or spoil.

The incorporation of organic matter or mulch into the upper layer of soil or spoil is beneficial for both improved nutrient- and water-holding capacity. Materials such as steer manure, straw, hay, peat moss, and other organic matter have been used successfully (Brown and others 1976, 1978).

If the soil pH is lower than about 5.0, lime or calcium carbonate should be applied in sufficient amount to raise the pH to about 5.5 or 6.0. Soil pH above 5.5 ensures that residual nutrients and applied fertilizers will be available to the developing plants, and that aluminum concentrations will be unavailable for uptake. Soil acidity tests performed by soil testing laboratories can provide data that recommend liming or calcium carbonate application rates necessary to neutralize acidity (Jurinak 1982). This amendment should be applied at the same time as fertilizer, and should also be incorporated into the upper 15 or 30 cm of soil. Brown and Johnston (1980) used 2,240 kg/ha of hydrated lime on the McLaren Mine in southwestern Montana to successfully adjust soil pH above 5.0 before revegetation. However, exact quantities required vary widely with specific site conditions.

Seeding and Planting Methods

Seed mixtures of several species should be applied on the site after fertilizer and other amendments have been incorporated into the soil. Optimum seeding rates on high-elevation disturbances normally range from about 225 to 550 total seeds per m^2 depending on the species used and site conditions. Generally, the seed is distributed uniformly with a hand-operated distributor or broadcast by hand over the surface of the site, and then covered by light raking or harrowing. Brown and Johnston (1980) used a commercial seeder-packer on a subalpine mine site to cover the seed to a depth of about 1 cm. Packing ensures firm contact between the seed and the soil particles, which appears to enhance germination. Species requiring light for germination (Haggas and others 1987) should be applied on the surface separately after the other species are seeded and packed. Seeding should be done during relatively calm periods to minimize wind redistribution.

Transplanting offers an alternative to seeding, and in some cases may be desirable in combination with seeding. Plant survival rates tend to be high when transplanting is accomplished in the fall with dormant containerized stock, and when rigorous planting procedures are followed (Brown and Johnston 1980). Plants may be grown from seed in a greenhouse or nursery as tublings, and then transported to the site for hardening and planting. Additionally, sod pieces collected from old road cuts or other disturbances can be collected and transplanted directly on the disturbed site (Brown and others 1976, 1978). Although survival of transplants can be high, transplanting tends to be very expensive and should probably be restricted to small key disturbances where slopes are too steep for seeding and where erosion hazards are high.

Surface Mulching

Surface mulching is recommended following seeding to moderate the effects of wind redistribution of seed, reduce evaporation, and minimize the effects of frost on seedling development (Brown and Johnston 1979, 1980; Chambers and others 1988). Materials such as straw or hay held in place with either pinned netting or an emulsion agent have been used successfully (Brown and Johnston 1979, 1980; Chambers 1987). Surface mulches should lightly cover the soil, yet still allow light to penetrate to the soil surface (Brown and Johnston 1979).

RESEARCH NEEDS

Although techniques for revegetation of high-elevation disturbances appear to be successful, additional research is needed as these life-zones come under increasing pressure from a wide variety of uses. Identification of adapted native species and an understanding of their physiological tolerances and ecological characteristics remain some of the most urgent needs. We need a better understanding of successional processes on disturbances, including the effects of competition and of nutrient and water relations requirements and interactions. In addition, we need to understand the characteristics and long-term interactions that mycorrhizal and nitrogen-fixing symbionts have with other adapted species on disturbances.

Further research is needed on the long-term effects of various reclamation methods, including soil amendments, and the effects they have on species performance and interactions and on soil nutrient retention and cycling. Studies on soil weathering and development and the dynamics of heavy metals and other toxic materials as they interact with plants are needed. Present methods appear to be inadequate for successfully revegetating the most extreme acidic mine spoils in the alpine zone throughout the West. Thousands of hectares of abandoned pyritic mine dumps and tailing piles throughout the mountainous West are located in the headwaters of watersheds from which increasing demands are being made as metropolitan areas expand. These, together with new mines and other disturbances, are degrading water quality of streams, rivers, and reservoirs throughout the region. Clearly, reclamation research of high-elevation disturbances needs to be expanded and intensified.

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LANDSCAPE- AND ECOSYSTEM-LEVEL MANAGEMENT IN WHITEBARK PINE ECOSYSTEMS

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ABSTRACT

To provide adequate resource protection in alpine and subalpine areas, managers need to expand their perspectives and focus on ecosystem and landscape-level management. Single-resource and microsite focuses stymie integrated management and protection plans. A landscape perspective is outlined for the Northern Rocky Mountains, interpreting climatic, landform, topographic, and distribution factors and their relation to vegetation mosaics.

INTRODUCTION

The upper subalpine and alpine zone of the Northern Rocky Mountains has a unique natural vegetation mosaic. This mosaic of forested and nonforested communities differs from the montane forested and nonforested community mosaic that occurs in the next lower elevation zone. The alpine and subalpine community mosaic is a diverse complex of subalpine forest-dominated upland communities, shrub- or herb-dominated upland communities, shrub- or herb-dominated wetland communities, and talus, scree, or rock cliff areas, with sparse vegetation cover.

The types of community mosaics within the alpine/ subalpine zone vary by geographic area and type of disturbance history, and are strongly correlated with topography and amount of soil development. A second process of importance is presettlement and postsettlement fire history. Differences between geographic areas exist, both in the natural potential for fire ignition and spread and in the history of fire suppression. A third process that produces different types of mosaics is disturbance by humans, which in this zone, typically includes timber harvest, roads, mining, effects of pollution, effects from recreation, and livestock grazing.

Managers and researchers face a difficult challenge in this zone. It is imperative that we take a landscape perspective and ecosystem management approach to maintain a diversity of productive and functioning ecosystems. Yet the nature of resource advocacy and studies that emphasize small, uniform areas stymie our ability to manage ecosystems at a broad-scale level with an integrated approach. Our basic management objective should be land stewardship that protects the basic ecosystem values of soil, water, air, biotic diversity, and ecological processes, while producing resources for public use. To protect these values and provide resources it is logical to move forward in understanding and implementing an ecosystem management approach at a landscape level.

The understanding of communities and their linkages at a landscape level is a developing science. This paper will provide a landscape perspective of subalpine and alpine ecosystems in the Northern Rocky Mountains, interpret some of the effects of human activities on the landscape mosaic, and identify challenges for managers and researchers to meet to provide sound land stewardship of these ecosystems.

PRIMARY FACTORS OF LANDSCAPE MOSAICS

The pattern, shape, size, and juxtaposition of communities on a landscape are formed or controlled by a variety of factors (Bailey 1988). These factors range from broad-level factors, such as change in climate, to site-specific factors, such as effects of fire, insects, or windthrow (Knight 1987). Broad-level and community-specific factors interact to result in a dynamic pattern of shifting community shapes and sizes. This spatial and temporal pattern is an important component in the development of management strategies.

Geographic and Climatic Patterns

Different geographic areas have different spatial and temporal patterns on their landscapes within the subalpine and alpine zones. Within the Northern Rocky Mountains there is a strong west-to-east longitudinal gradient and a strong south-to-north latitudinal gradient that create different patterns as a result of changing climate conditions (Arno and Hammerly 1984). From west to east, subalpine and alpine climates shift from inland-maritime, to semidesert, to continental influence. From south to north in the Northern Rocky Mountains the lower elevational limits of the subalpine and alpine zones tend to decrease with elevation. However, this can be strongly influenced by local relief and wind patterns.

Landform Patterns

Local landforms and valley to mountaintop relief strongly influence the climate of the subalpine and alpine zones (Arno and Hammerly 1984; Habeck 1987). The

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present landform landscape is an interaction of the landforming process with the geological bedrock and previous landforms (Bailey 1988). In subalpine and alpine areas glaciation is a common important landforming process. Areas that had significant mountain glaciation that covered all aspects differ considerably from areas that had minor mountain glaciation or nivation snow basin action on north slopes, but were not glaciated on alpine plateaus or southerly aspects. Other areas on the northern end of the Northern Rocky Mountains that were strongly influenced by both continental and mountain glaciation have a different landform landscape.

Areas that have low-elevation valleys associated with high-elevation mountains appear to differ significantly in their subalpine and alpine landscape from those areas where the valleys are relatively high elevation and the relief difference from valley to mountaintop is not as great. Those areas that have large relief differences usually have sharper gradients in the alpine and subalpine zone and often have higher precipitation.

Topographic and Edaphic Patterns

Aspect, slope, and soil have a strong influence in the alpine and subalpine zone. The slope, aspect, and position of a community determine microclimatic influences that create a highly complex set of conditions across relatively small land areas. This results in an intricate pattern of variation within and between communities.

Many plants in the subalpine and alpine zone are on the edge of their ecological amplitude. Consequently, minor shifts in soil characteristics that change soil physical and chemical conditions can affect the ability of plants to survive and compete. This results in high variability within and between communities.

Natural Disturbance and Cycles

Natural disturbances and successional cycles, or sequences, cause dramatic changes in the spatial and temporal patterns of subalpine and alpine communities. Natural disturbances of fire, wind, drought, severe cold, erosion, animal herbivory, and mortality or reduction in vigor from insect or disease influences all interact to result in dynamic conditions in this zone. Vegetation composition over time, as a result of interacting plant species growth rates, competitive ability, and mortality, also changes over time as influenced by the various disturbance factors. In the subalpine and alpine zones, where plant growth rates are slow and competitive ability is low, disturbance factors are often harsh and play a strong role in maintaining a dynamic set of shifting conditions. But alpine plant communities have a relatively low ability to buffer against these changes, in comparison to lower elevation montane and valley systems.

Landscape Linkages

The mosaic of ecosystems in a landscape has linkages of: (1) snowmelt and water flow, (2) energy state and transfer, (3) nutrient state, cycling, and transfer, (4) animal habitat needs and movement, and (5) buffering from disturbance. In systems such as the subalpine and alpine zones, which are subjected to extreme environmental conditions, these linkages are critical for species and community survival. Changes in community juxtaposition or conditions can shift the environmental balance and negatively affect an associated community to the point where it can no longer survive. An example in the alpine and subalpine zones is the moist herbaceous communities typically associated with the lee side of a patch of subalpine trees or timberline krummholz trees. Removal of the patch of trees through fire or other disturbance eliminates the conditions for snow retention in the adjacent community, which changes the moisture, energy, and temperature conditions in that ecosystem.

Human Disturbance

Impacts from human developments, pollution, and disturbance to natural processes have been relatively low in the subalpine and alpine zones compared to other ecosystems. However, these zones are very sensitive to disturbance by humans, and the consequences are often highly visible. Primary human disturbances that have affected the subalpine and alpine ecosystems involve: (1) mining, (2) oil and gas development, (3) road construction, (4) direct fire suppression impacts, (5) indirect fire suppression effects, (6) domestic livestock grazing, (7) logging, and (8) air pollution and associated global climatic change. Because of the lack of buffering ability in subalpine and alpine ecosystems, the effects of these disturbances are longer, often more drastic, and tend to be more chain-reactive than in other more productive and less fragile ecosystems.

The principal effects of historic natural resource management and development on landscape patterns and linkages have tended to fragment communities that are naturally contiguous and reduce or eliminate corridors or environmental linkages between associated ecosystems (Franklin and Forman 1987; Knight 1987). In contrast, the consequence of fire suppression in relatively natural landscapes has been homogenization. Typical patterns of human developments are straight lines, squares, and rectangles compared to the more natural shapes of nature.

In Europe, long-term human developments have resulted in a lowering of the upper timberline, thus increasing the alpine zone (Douguedroit 1978; Plesnik 1978). This has been primarily caused by tree cutting for use in charcoal burning and by grazing. Some attempts have been made to reforest these areas with subalpine tree species. These attempts have been somewhat successful in establishing trees in this zone, but the resulting forests greatly lack the natural diversity of patterns and associated stability of linked communities.

In the Northern Rockies, historic logging, mining, and livestock overgrazing have locally removed forest subalpine communities and changed community patterns. However, these effects have not been broad scale. Revegetation of sites degraded by mining, roading, and overgrazing has been somewhat successful given the right conditions. It has become apparent that once the shallow

topsoil is lost, revegetation of alpine and timberline ecosystems is very difficult. The change in snow accumulation/melt patterns and energy flow from tree removal and soil loss in these ecosystems often create a complete change in the potential vegetation that can grow on the sites.

Disturbances to subalpine forest vegetation from logging and overgrazing set succession back to an early stage. As long as the disturbance has replicated natural events, such as fire or big-game grazing, and no exotic plants have been introduced, succession will usually proceed in a relatively natural fashion. However, successional response in this zone is very slow, even when there has been no effect on soil and microclimate. This slow response usually does not meet management standards for regeneration or for livestock vegetation management trend. There is little that can be done to speed up this response on areas that have been impacted in the past. Future harvest treatments and grazing systems should be designed to better mimic natural disturbances and maintain soil productivity and microclimate conditions.

The results from fire suppression in the subalpine zone are broad scale. Natural fire frequency cycles are relatively long in this zone and successful ignitions are infrequent (Arno 1986; Fischer and Bradley 1987). Consequently, fire suppression has been relatively successful. Since fire frequencies are typically 100 to 300 years, the effects of fire suppression on individual communities have not caused a change from what is present naturally. The primary effect is that the amount of communities in an early seral stage compared to mid and late seral is much less. Consequently, the pattern of communities in this zone is becoming more homogenous; old communities are maintained, while adjacent communities that were once young are now becoming old.

Intensive development and management by humans usually result in a reduction of genetic and species diversity. In the subalpine and alpine zones of Europe this has been a significant result from long-term degradation of these environments (Douguedroit 1978; Plesnik 1978). Many species have become extinct, and the diversity of species in existing communities is much lower than in similar natural communities.

In the Northern Rocky Mountains there have been relatively few plant species extinctions in the alpine or subalpine zones that have been caused by human developments or management. In localized communities that have had severe impacts from mining, road building, or overgrazing there has been significant loss in species diversity. Where exotic species have been introduced, there is little chance for the native species to compete and reestablish dominance through succession.

There is little doubt that pollution is affecting our natural communities (Mintzer 1988; Perry and Maghembe 1989). There is ample evidence that acid rain and other pollutants are reaching all environments on earth. Some ecosystems have the ability to buffer these pollutants and will not be strongly affected. Ecosystems at extremes, such as the subalpine and alpine zones, that have little buffering ability, are typically the first to demonstrate effects of these pollutants. There is little agreement on how global climates may change. However, it is generally agreed that climates will become more extreme even if there is little change in the averages. The subalpine and alpine climates will be more sensitive to this change and communities may show the effects. These ecosystems should make excellent monitoring sites that would be sensitive to changes in air pollutant levels and climates.

EVALUATION AREAS

Three areas were selected on a west-to-east gradient at approximately 46 °N. latitude across the Northern Rocky Mountains. All areas have had varying degrees of mountain glaciation and have subalpine and alpine vegetation, with some communities dominated by whitebark pine (*Pinus albicaulis*). Areas were mapped and map photo interpretation types were correlated with available ground data. The furthest west area is an area on the south end of the Seven Devils Mountains of north-central Idaho, which lies between the Snake River to the west and the Little Salmon River to the east. The second area, which is in west-central Montana, near the Continental Divide, is in the Bitterroot Range, and is called the Piquette Mountain area. This area lies between the East Fork and West Fork of the Bitterroot River. The third area is in south-central Montana, west of the Boulder River, and is called the Meatrack-Carbonate area.

The three areas all have had historic sheep grazing impacts, but adequate areas were left ungrazed to compare disturbed to natural vegetation. All three areas also have had some disturbance from past exploratory mining, but this is relatively minor when compared to the size of the total area.

Table 1 shows a comparison of various environmental and landscape factors based on a preliminary assessment. A final assessment will be published at a later date based on additional ground data and correlation.

Climates of the three areas make a transition from strong maritime influence on the west to the continental climate of the Meatrack-Carbonate area on the east. The Seven Devils site has strong evidence of glacial cutting or deposition on most of the area. The Piquette Mountain area shows evidence of glaciation primarily on the northerly aspects and on south aspects at the highest elevations. Both of these areas have alpine communities that are on steep slopes or in cirque basins. The Meatrack-Carbonate area has strong evidence of glaciation on the north aspects and some south aspects, but large areas of high-elevation alpine plateaus remain above the glacial cirques.

The area with the highest relief is the Seven Devils area with a low of 1,600 ft at the Snake River to a high of about 8,500 ft. The other areas have differences of relief of about 5,000 ft; the Meatrack-Carbonate rises almost 2,000 ft higher than the Piquette Mountain area.

Potential vegetation indicated a strong dominance by forest communities in the Piquette Mountain area compared to approximately an even split between forest potential and nonforest potential on the Seven Devils area. The Meatrack-Carbonate area showed strong dominance by herbaceous communities. This is probably correlated with the low precipitation and continental climatic regime. The presence of subalpine shrub types, primarily

Table 1—Environmental and landscape factors for three subalpine/alpine areas in the Northern Rocky Mountains

Factor	Area		
	Meatrack-Carbonate	S. Seven Devils	Piquette Mt.
Climate type	Inland-maritime	Inland-maritime	Continental
Valley elevation (ft)	1,600	3,500	5,500
High elevation (ft)	8,500	8,600	10,500
Percent mt. glaciation	85	50	35
Percent subalpine forest potential	45	60	30
Percent subalpine herb potential	15	15	30
Percent subalpine shrub potential	15	5	0
Percent timberline krummholz	5	2	10
Percent alpine herb-shrub potential	5	3	15
Percent rock, scree, and cliff	15	15	15
SI(50) SAF ABLA/VASC HT	44	33	22
BA (ft^2) ABLA/VASC HT	115	145	175
Herb-shrub foliage production (lb)	955	785	1,060

mountain sagebrush (*Artemisia tridentata vaseyana*), appeared to be strong to the west and decreased to the east. All areas had approximately the same amount of rock, scree, and cliffs.

Site index and basal area of subalpine fir (*Abies lasiocarpa*) were evaluated on a subalpine fir/grouse whortleberry habitat type (Pfister and others 1977; Steele and others 1981) on all three areas for similar aspects. There is considerable difference in soils between the three areas. Site index (SI) generally decreased from west to east for subalpine fir, as would be expected, making the transition to a drier and more continental climate. Basal area generally increased from west to east, and no correlation can be drawn since this attribute is probably more highly correlated to past stand history than to the environment. Production of annual herb and shrub foliage (lb/acre) was evaluated on an elk sedge/Idaho fescue grassland type for all three areas. This value should generally increase in correlation with continental climate, but there was considerable difference in soils and precipitation.

A preliminary assessment of polygon shape and size was also conducted for the three areas. These preliminary values are presented in table 2.

Size and shape of polygons for different vegetation types were highly variable between the areas and showed no strong correlation with the west to east climatic trends. Size, shape, and juxtaposition appear to be highly correlated to local factors of landform, topography, soils, and historic disturbance. Table 3 shows a relative correlation of these factors for the three areas that were evaluated. Fire appears to be a much stronger component in the Seven Devils and Piquette Mountain areas compared to the Meatrack-Carbonate area. However, that may be an incorrect conclusion, since although fires may be less frequent in the Meatrack-Carbonate area, they may just as strongly control size and shape over the long term.

Methods for assessing these correlations are relatively rough and need to be refined to better identify controlling factors and explain variability. Statistical parameters to describe variability are difficult to assess, since none of the factors can be considered to have normal distributions. Frequency statistics appear to be the primary attributes that are descriptive and have meaning for making management assessments and recommendations.

Table 2—Polygon size and shape factors for three subalpine/alpine areas in the Northern Rocky Mountains

Factor	Area		
	Meatrack-Carbonate	S. Seven Devils	Piquette Mt.
Polygon shape			
Subalpine forest types			
Mean size (acres)	45	80	20
Percent linear	30	45	15
Percent octagonal	35	20	40
Percent elliptical or oblong	25	25	30
Percent rotund	5	0	10
Percent irregular	5	10	5
Percent rectangular	0	0	0
Whitebark pine types			
Mean size (acres)	35	10	15
Percent linear	40	85	25
Percent octagonal	40	5	15
Percent elliptical or oblong	0	0	20

Table 3—Percent correlation of factors controlling polygon size and shape for three subalpine/alpine areas in the Northern Rocky Mountains

Factor	Area		
	Meatrack-Carbonate	S. Seven Devils	Piquette Mt.
	Percent		
Geoclimatic	5	5	5
Landform	15	30	30
Topography	15	25	30
Soils	20	5	15
Disturbance	45	35	20

MANAGEMENT AND RESEARCH CHALLENGES

There are many challenges for management and research in the subalpine and alpine ecosystems. We need to evaluate our ability to manage ecosystems from a landscape and vegetation perspective. Do we have the technology and the philosophy to take this approach? Another way to ask this question is "do we see the ecosystem for the trees?" If we had all the data we needed to describe ecosystems from a landscape perspective, would we have the techniques to analyze those data? We need to develop the ability to assess natural mosaics relative to "human activity" mosaics and determine the positives and negatives of various combinations of vegetation types, their size and shape, their juxtaposition, and associated corridors or linkages.

Now more than ever, managers must develop an ecosystem philosophy for management. The number one objective for managers of public lands should be to provide land management and stewardship that protect and enhance basic values (soil, water, air, biotic diversity, natural processes), while producing resources for public use.

On the forefront of management and research challenges is the need to take an ecosystem and landscape approach to assessing management alternatives. Managers must develop their abilities to analyze ecosystems and develop integrated alternatives, rather than being advocates for their own specialty. Specific resource advocacy is a detriment to an ecosystem approach and results in interdisciplinary team members "whipsawing" each other from defensive to offensive, and alternatives to mitigation.

To develop effective management alternatives and understand their potential effects, management needs to be able to extrapolate to large-scale areas. Present research is often done at a micro scale, and management lacks the tools to interpret the results at a large scale. Research needs to develop the relationship between predicting results for a site to extrapolation for an ecosystem.

Research should begin developing technology to assess spatial and temporal changes and assess how these changes might affect resource outputs, community linkages, and ecosystem stability. Without this technology it will be difficult to develop viable ecosystem management alternatives that will provide for conservation of natural processes, landscapes, ecosystems, species, and genetic resources. With this technology managers can develop prescriptions for landscapes versus stands or communities.

To summarize, the challenge to managers is to expand their perspective to the ecosystem and be their own conscience for protection of basic ecosystem values. The challenge to researchers is to improve our ability to extrapolate results, and assess alternatives and affects, in the realms of both spatial and temporal landscapes.

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SESSION 5

Where Do We Go From Here?

Tad Weaver and Wyman C. Schmidt
Session Coordinators

This session served as a wrap-up for the symposium and described how the Forest Service and National Park Service, who manage the preponderance of whitebark ecosystem lands in the United States, view the management and goals for these lands. It also includes an examination of the knowledge gaps and research needs that became apparent as a result of the symposium as well as some highlights of what was learned.

INTEGRATING WHITEBARK PINE INTO NATIONAL PARK MANAGEMENT GOALS

C. J. Martinka
K. A. Keating
C. H. Key

ABSTRACT

Various relationships between ecosystems, National Parks, and whitebark pine (Pinus albicaulis) *are discussed. Ecosystem management in and around parks involves four elements: (1) expression of desired condition; (2) definition of boundaries; (3) management strategies; and (4) determination of effectiveness. Numerous factors have contributed to the complexity of environmental issues and the requirements for management accountability in National Parks during recent decades. Whitebark pine and western parks possess the potential for a mutually beneficial relationship with the species serving as an environmental barometer and the parks providing a foundation for conservation.*

INTRODUCTION

Mankind has always sought knowledge about the environment and applied it in a fruitful fashion to the ultimate of ecological imperatives—maintaining a livelihood. Historical motivation for the acquisition of new information was likely quite simple and directed almost entirely toward the exploitation of natural resources. More recently, conservation of those same supporting resources has emerged as a critical issue on a worldwide scale. And for the same reasons that drove exploitative behavior over the eons of history—sustaining a future for the human species.

Nearly the entire breadth of the conservation movement has occurred during the current century. Momentum has accelerated during recent decades when numerous Federal and State laws have been enacted to assure appropriate protection and management of natural resources. These laws reflect the conscience of a public concerned about the quality of life and its supporting environment. Extinctions have helped heighten an awareness of biological diversity and the role that individual species play in ecosystem integrity. Mammals have received a predominant share of scientific attention, but there is growing interest in other contributors to the trophic fabric of ecosystems. Whitebark pine (*Pinus albicaulis*) is taking its place on a growing list of plant species for which there are now legitimate reasons for gathering and evaluating new knowledge.

This paper discusses various relationships between ecosystems, National Parks, and whitebark pine. The unique attributes of the species suggest that it plays an important ecosystem role in the mountainous parks of the Western United States. At the same time, the parks will likely play an increasingly important role in management of the species as the global environment changes in future decades.

ECOSYSTEMS AND PARKS

In 1987, a group of managers, scientists, and planners gathered at Pack Forest, WA, to discuss and develop ecosystem management concepts for parks and wilderness. The published results of the workshop provide a rationale for ecosystem management and suggest means by which the concept might be implemented (Johnson and Agee 1988). Managing in an atmosphere of uncertainty was of special concern to the participants and a four-step process was recommended for addressing ecosystem goals for nature reserves.

Step one proposed that the desired condition for the ecosystem be expressed in terms of specific goals and measurable targets. Since past management has focused on protection as the principal means of conserving natural integrity, this element adds a new dimension to future strategies for most natural sanctuaries. Most certainly, the scientific process enters the management picture, but beyond that, the question of congruity between science and philosophy will likely emerge as a dilemma for many areas. In this sense, humans become an integral part of natural systems in terms of both their intellectual direction and their ecological impacts. Significant organizational changes will be required to add management to the essential foundation of protection for parks and wilderness.

Step two is a recommendation that ecosystem boundaries be defined using primary components for guidance. This goal is not only reachable but has been implemented in several settings using information from field studies of large mammals. For example, movements of grizzly bears (*Ursus arctos*) have helped define an ecosystem that includes a large area surrounding Yellowstone National Park (Craighead 1980). At the same time, reality points

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to the difficulties associated with using components such as migratory birds, continental airsheds, or river systems to define boundaries. Systems of sanctuaries are likely to be an important approach to solving the ecosystem boundary issue on continental or global scales.

Step three moves into the arena of management and recommends the development of strategies to achieve goals that transcend political boundaries. There is little doubt that the focus of this task on the human element will cause it to be the most difficult of the four that were presented. Many, if not most, natural resources tend to be shared by a number of adjacent managing agencies, but goals for species or communities are frequently in conflict. At least a part of the problem has been a rather pervasive attitude that ecosystem elements cannot be managed to satisfy more than one goal. Thus a sanctuary manager may not accept harvest of migratory ungulates as consistent with an objective of maintaining natural relationships with dependent carnivores. Rigorous application of scientific process and knowledge may help move this recommendation toward success.

Finally, the fourth step urges that programs to assess the effectiveness of management in meeting stated goals be implemented. Comprehensive inventories of natural resources to establish baseline ecosystem conditions as well as monitoring systems to assess trends of significant components are critical requirements of this program element. Unfortunately, park and wilderness management have tended to focus on the solution of specific problems; the systematic collection of facts about systems and relationships has typically been relegated to a subordinate role. Current interest in biological diversity, insular population ecology, and landscape management is beginning to alter that tradition in many National Parks. In fact, a knowledge of baseline conditions was thought to be critical to the protection of National Parks within the existing framework of public law (Keiter and Hubert 1987).

This discussion points to the rather obvious fact that ecosystem management in parks is an appropriate strategy for the future but that its implementation requires commitment to a new and complex form of public land administration. With this in mind, it seems essential that a foundation for ecosystem management be constructed in a way that fosters the building of a program in incremental steps. There is every reason to believe that evolution rather than revolution is the most likely pathway to successful land management using ecosystem concepts.

NATIONAL PARK ISSUES

From the National Park perspective, numerous reasonable and legitimate questions might be asked about ecosystem management as envisioned by those gathered at Pack Forest. Perhaps most important are those relating to the feasibility of an intricate new program that carries parks into what is essentially an organizational frontier. Of even greater concern is the almost total absence of factual information from which success for ecosystem management might be predicted. Yet it might also be noted that alternative solutions to the increasing complexity of park conservation have not been proposed, nor are any anticipated in the immediate future.

The recent history of Glacier National Park illustrates a number of changes that have become important elements in the development of a conservation strategy for the park and surrounding lands.

1. The park has become part of an increasingly fragmented natural system in northwestern Montana, a trend that is related primarily to the discovery, development, and use of natural resources. The change is clearly visible from the perspective of high-altitude photography and satellite imagery, but documentation of impacts in terms of ecosystem function remains a rather elusive goal.

2. The protection of rare and endangered species has evolved toward a general public interest in the conservation of biological diversity. In turn, requirements for the inventory of natural resources and monitoring of their status have intensified, especially in view of their demonstrated value in addressing major threats to regional ecosystem integrity.

3. The public has expressed its concern about environmental quality through numerous new laws that address a variety of conservation concerns. The enactment of these statutes has created legal alliances with other agencies that effectively carry park management into the regional setting for issues such as the protection of airsheds, water quality, and endangered species. Even the process of making decisions has been opened to public scrutiny through the National Environmental Policy Act.

4. Rapid advances in collection systems and computer technology have allowed the storage, processing, and retrieval of massive amounts of information about our parks. Using that information has become a challenge that is leading to even more complex programs such as geographic information and database management systems. In turn, continuing education is now a necessity among park staff that must cope with these new demands.

5. The very real prospect of global warming is causing park managers to adjust their thinking about future environments and how anticipated changes in extinction and colonization rates for sensitive species will be addressed. In fact, fundamental philosophies are being questioned by some who now feel that human intervention to assure the attainment of desired conditions will be predominant in the management process.

6. The role of parks is expanding to include scientific values as part of their management strategies (Martinka 1985). These values were recognized in the enabling legislation for many parks, but only recently has the scientific process emerged as an important part of park management programs.

At this point, park science deserves further discussion, since its functional role is both new and dynamic. For example, emphasis is shifting from describing the biology of species to understanding the nature of systems. In turn, park scientists now tend to focus their efforts on regional or even continental study areas rather than confining their activities within ecologically arbitrary park

boundaries. And stored information holds unique potential for research with geographic information systems providing the processing tool for design, evaluation, and synthesis of study problems. Each of these changes is significant in terms of the ecology and management of whitebark pine.

WHITEBARK PINE

Whitebark pine is one of thousands of plant species that inhabit numerous National Parks throughout the Western United States. It has not been a species of special concern until recent surveys pointed to locally significant population declines. The combined effects of insect infestations and fungal disease likely promoted the severity of the losses, which are especially visible in subalpine forests. At the same time, survival of this hardy tree as a species has not been seriously questioned.

One benefit of the population decline has been the recognition that whitebark pine possesses attributes that make the species unique in terms of National Park management strategy. It is adapted to the extreme climate and poor soil of high mountains. The species grows slowly, has a long life, and tends to have a patchy distribution, locally and throughout its range. At the same time, seed crops are sufficiently abundant to provide an important food source for birds and animals. These characteristics point to whitebark pine as a possible candidate species for monitoring park ecosystems. A rationale for use of this particular species as a monitor includes the following elements:

1. Its high-altitude ecological niche is likely to be sensitive to habitat changes, especially those induced by atmospheric disturbances such as acid deposition or climatic change.
2. Its patchy distribution provides inherent potential for experimental design and statistical treatment when developing monitoring programs.
3. Trophic relationships to species such as grizzly bears and red squirrels (*Tamaisciurus hudsonicus*) are simple and direct, an attribute that enhances the value of whitebark pine as monitor of ecosystem health.

No one species provides all the elements necessary for a complete environmental monitoring program, but it is likely that whitebark pine would rate high in ranking systems that might be developed in the future.

IMPORTANCE OF PARKS

Discussions to this point have focused on the value of whitebark pine to National Parks. It now seems appropriate to view the reverse relationship—the value of parks to whitebark pine.

First, one can and should value the National Parks for their ability to provide baseline information against which the experiments of exploitative or manipulative management can be compared. This is an inherent value that is currently in its infancy in terms of practical application. However, regional programs to manage natural resources will require comparative baseline information if they are to have a rational basis for assessing the attainment of stated goals.

Second, the parks serve as refuges for whitebark pine and other species as disturbance and change occur on surrounding lands. This is not to suggest the possibility of extinction for whitebark but rather to address the issue of reduced genetic diversity under the various forms of management and environmental stress to which the species is currently subjected. Parks may help conserve that diversity and thereby provide a source of genetic material for restoration of the species over regional landscapes at some point in the future.

Finally, parks may serve as retreats for the distributional changes that are predictable as a result of global climatic change. In this case, suitable habitats are protected along climatic gradients within and adjacent to the current range of the species. Natural or anthropic seed dispersal would carry the species to new habitats as climatic changes occur. This issue is of special interest, since it elevates treatment of a single species to the level of landscape management.

CONCLUSIONS

Whitebark pine is an important subalpine tree in many of the National Parks of the Western United States. The species possesses attributes that contribute to its potential as a monitor of ecological conditions in the parks. At the same time, it appears that parks may play an important role in future conservation of this unique tree. The mutually beneficial relationship between a species, protective sanctuaries, and landscape management is likely to become a common model for the future.

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A SURVEY OF WHITEBARK PINE MANAGEMENT ON NATIONAL FOREST LANDS

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ABSTRACT

Whitebark pine (Pinus albicaulis) *occurs in 25 National Forests in the Western United States. Although this species is of limited commercial value throughout its range, the ecosystems in which it is a major component are highly valued for wildlife, watershed, and esthetics. This paper reviews the results of a questionnaire on past and current management direction regarding* P. albicaulis *on National Forest lands as perceived by 20 Forest Service ecologists, soil scientists, and silviculturists, and discusses how this direction may change to meet future concerns.*

INTRODUCTION

Whitebark pine (*Pinus albicaulis* Engelm.) is a component of high-elevation ecosystems across approximately 25 National Forests in the Northern Rocky Mountains. Although of limited commercial value throughout its range, the ecosystems where it occurs are highly valued for wildlife habitat, watershed, ecological diversity, and esthetics (Arno and Hoff 1989).

Management direction toward whitebark pine on National Forest lands is a function of the harsh climate where these ecosystems are found. High elevations and wilderness designations preclude most intensive management options. These conditions, however, do not negate concerns of land managers as documented in this symposium and in papers by Arno and Hoff (1989), Eggers (1985), and in unpublished Forest Service, U.S. Department of Agriculture, letters (Hamilton 1989; Hann 1989).

While this symposium focuses on whitebark pine, it is important to recognize, as Schmidt (1987) has pointed out, that whitebark pine has ecological counterparts, which occupy similar habitats in North America and Eurasia. European stone pine (*Pinus cembra*), is one such species (see Holtmeier this proceedings). Two North American counterparts are limber pine (*Pinus flexilis* James) and bristlecone pine (*P. aristata* Engelm.); these both occur in National Forests.

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The results of a questionnaire on past, present, and future whitebark pine management in National Forests, as perceived by 20 Forest Service ecologists, soil scientists, and silviculturists, are presented and discussed.

QUESTIONNAIRE

To identify Forest Service perceptions, a questionnaire was developed. This questionnaire was mailed, using the Forest Service computer network, to specialists that have worked or are working in whitebark pine ecosystems. Twenty completed surveys were returned representing 25 National Forests. The discrepancy in numbers can be accounted for by zone or regional office responses. Another 10 people responded with short messages or by providing internal memos on the topic. This survey was not intended to be represented as statistically sound. At best, it is subjective, but does give an indication of field personnel concerns. The questions asked and a summary of the responses follow.

QUESTION 1

How would you rate (no or low, moderate or high) the following concerns (past, present, future) about whitebark pine ecosystems? Also rate each for the need for more research.

Table 1 summarizes the results of responses to this question.

Grizzly Habitat

Of foremost interest in the Northern Rocky Mountains is grizzly bear habitat relationships. This concern has given impetus to the study of whitebark pine in National Forests in recent years.

The responses indicated that grizzly bear habitat concerns within whitebark pine ecosystems could be divided between those Forests that express no or low concern and those expressing moderate to high. Naturally, Forests within or close to grizzly habitat show greater interest because of the high food value of whitebark pine seed crops. Conversely, those Forests not within occupied habitat are not as concerned. However, this would change with the possibility of reintroduction and expansion of grizzlies to their historic ranges. Only Forests within occupied grizzly habitat were addressed below.

Table 1—Question 1, summary of responses by percentage

Category	Past	Present	Future	Research
Grizzly habitat	[1]50(50)	30(70)	20(80)	20(80)
Regeneration	88(12)	61(39)	34(66)	45(55)
Fire effects	83(17)	55(45)	44(56)	56(44)
Cone production	100(0)	72(28)	50(50)	66(34)
Silviculture concerns	94(6)	72(28)	61(39)	50(50)
Recreation concerns	61(39)	44(56)	17(83)	39(61)
Visual concerns	77(23)	39(61)	34(66)	61(39)
Plant succession	89(11)	61(39)	50(50)	39(61)
Insect and disease	83(17)	83(17)	61(39)	56(44)
Classification	76(24)	65(35)	47(53)	59(41)
Watershed	72(28)	55(45)	34(66)	56(44)
Livestock grazing	78(22)	78(22)	83(17)	89(11)
Nongame	89(11)	78(22)	62(38)	67(33)
Big game	76(24)	64(36)	53(47)	65(35)

[1]Percent of respondents, first number indicates no to low concerns, ( ) indicates moderate to high concerns.

Fifty percent responded that there was moderate to high concern for grizzly habitat in the past and 50 percent said there was at least a low concern. This increased to where 70 percent now have high concerns. In the future, 80 percent envisioned having high to moderate concerns. Research needs were categorized as 20 percent low, 40 percent moderate, and 40 percent high.

Regeneration

Understanding the basic growth requirements for whitebark pine seedlings and how these plant communities are established is an important basis for many management decisions.

Only 12 percent indicated moderate to high concerns about regeneration in the past. This increased to 39 percent for present and 66 percent for future concerns. Fifty-five percent felt research in this area should have a moderate to high priority.

Fire Effects

The Greater Yellowstone fires of 1988 focused the attention of land managers on the consequence of fire in these ecosystems. Fire may have beneficial effects in whitebark pine ecosystems, but what will be the effect of fires of that magnitude on these ecosystems?

The responses show that only 17 percent had moderate to high concerns about fire effects in these ecosystems in the past. This has increased to 45 percent for present and 56 percent for future concerns. Forty-four percent felt there was a moderate to high priority for research in this area.

Cone Production

Cones from whitebark pine are an extremely important wildlife food (Reinhart and Mattson, this proceedings; Tomback and others, this proceedings). Poor seed crop years may affect the whole ecosystem from grizzly to bird and small mammal populations.

The survey indicated interest in cone production in the past was very low; 100 percent of the responses expressed no or low concerns. This changed with research documenting the value of whitebark pine seed crops to wildlife. Twenty-eight percent now feel that cone production is a moderate to high concern. This interest increased to 50 percent when the question about the future was posed. Thirty-four percent felt that there was a moderate to high need for more research in this area.

Silvicultural Concerns

Where whitebark pine communities are adjoining commercial timberland, as in the Shoshone, Bridger-Teton, and Lolo National Forests, there may be opportunities for silvicultural prescriptions to obtain desired habitat conditions and possibly increase the range and cone productivity in specific areas. These practices have been suggested by Eggers (1985, this proceedings) and Hamilton (1989), but would be costly and their practicality may be questionable in inaccessible areas.

Only 6 percent indicated that silvicultural concerns in these ecosystems were of a moderate concern. This increased to 28 percent at present and 39 percent in the future having moderate to high concerns. Fifty percent felt that there was a need for more research in this area.

Recreation and Visuals

High-elevation forests have high recreation and visual values. Commonly, these fragile whitebark pine habitat types are popular areas that receive heavy pressures from hikers, anglers, hunters, campers, and horse traffic. Frequently, these sites are depleted of firewood and soil erosion and compaction problems exist. Rehabilitating these sites is a critical factor in some intensely utilized and visually sensitive areas. Maintaining vegetative diversity and visual integrity is a consideration for any project involving these types.

Thirty-nine percent felt that there were moderate to high concerns regarding recreation in these ecosystems in the past. This increased to 56 percent for the present and 83 percent for the future. Sixty-one percent felt that there were moderate to high needs for further research in these areas.

Twenty-three percent felt that in the past visual quality was a moderate to high concern. This increased to 61 percent for the present and 66 percent for the future. Thirty-nine percent felt research was a moderate to high priority.

Plant Succession

Whitebark pine habitat types moving into late successional stages are being replaced by more shade-tolerant species such as *Abies lasiocarpa* and *Picea engelmannii*. Suppression of fire has allowed the conversion of many of these types (Arno and Hoff 1989; Morgan and Bunting, this proceedings). On the other hand insects, disease, and large fires have affected many acres (Kendall and Arno, this proceedings; Wellner 1989). Natural regeneration

on these harsh sites can be a long-term process and it may be several decades before significant cone crops are produced. Research in successional pathways is needed to fully understand what management options are available.

Eighty-nine percent felt that plant succession was not a concern in the past. Thirty-nine percent felt that this was now a moderate to high concern. Fifty percent felt that their future concerns will be moderate to high. Sixty-one percent said that research in this area was a moderate to high priority.

Insect and Disease

Mountain pine beetle (*Dendroctonus ponderosae* Hopkins) and white pine blister rust (*Cronartium ribicola* Fisch.) have severely affected many whitebark pine ecosystems. Epidemics have diminished some local populations of whitebark pine in northern Idaho and Montana (Arno and Hoff 1989; Kendall and Arno, this proceedings). Certainly, this is affecting cone crops and influencing successional trends over much of the range of whitebark pine. With the potential of white pine blister rust spreading into the Greater Yellowstone ecosystem, interest in this area will increase.

Seventeen percent responded that insect and disease problems were a moderate concern in the past. This remained the same for the present and then increased to 39 percent for future concerns. Forty-four percent felt there was a moderate need for research.

Vegetation Classification

To be able to communicate and compare solutions to resource problems, professionals need to be able to classify the landscape and its associated plant communities and soils. Certainly, this has been illustrated throughout this symposium by people discussing vegetation and ecological classifications. These classifications must be translated into maps of the landscape that allow land managers to assess the extent, productivity, and successional status of vegetation types.

Twenty-four percent felt that classification was a moderate to high concern in the past. This increased to 35 percent as a present concern and 53 percent as a future concern. Forty-one percent said that research was a moderate to high priority in this area.

Watershed

Whitebark pine ecosystems have very high watershed values. These high mountain areas are important for water storage and maintaining flow for downstream uses. Skiers, snowmobilers, and snowshoers also enjoy the heavy snowpack characteristic of these environments.

Only 28 percent had moderate or high concerns for watershed in the past. This increased to 45 percent for present and 66 percent for the future. Forty-four percent felt research had a moderate to high priority.

Livestock Grazing

At the turn of the century, high elevations often were heavily used by sheep. This resulted in deterioration in range by soil compaction and erosion in many instances. Although such sheep grazing is much less prevalent now and hopefully better managed, it still occurs along with some cattle grazing (Hall 1989; Johnson, this proceedings; Wellner 1989; Willard, this proceedings).

Only 22 percent felt that this was a concern in the past. This could be a function of time since this was strongly commented on by two retired Forest Service employees, Chuck Wellner (1989) and Fred Hall (1989). Concerns in this area remained low for present (22 percent), future (17 percent), and research (11 percent).

Nongame and Big Game

Whitebark pine ecosystems are used for summer range by deer, elk, and other wildlife. The role of Clark's nutcracker in seed distribution and significant use of squirrel middens by grizzly bear exemplify how land managers must consider the entire ecosystem when making management decisions.

The survey showed that only 11 percent had moderate or high concerns for nongame in the past. This increased to 22 percent for the present and 38 percent for the future. Thirty-three percent felt that research was a moderate priority.

Twenty-four percent had a moderate concern for big-game habitat in these ecosystems in the past. This increased to 36 percent and 47 percent with moderate and high concerns for the present and future. Thirty-five percent felt that research was a moderate to high priority.

Other Concerns

Other concerns not mentioned in the questionnaire, but brought up in comments, included problems in fuel management, global warming and subsequent species shifts, maintaining biodiversity, and the effects of changing air quality on high-elevation forests.

To summarize responses to the first question, the areas indicated as most important were visual quality, grizzly bear habitat, recreation, watershed, and fire effects. A conclusion drawn from these responses is that what is perceived as important by field people is not necessarily what this symposium has shown to be of critical interest. This is particularly true with respect to insect and disease problems and the importance of nongame species in the dissemination of seed.

QUESTION 2

What, if any, critical information is needed to enable your Forest to improve planning for whitebark pine ecosystems?

Responses indicated that information was needed on successional status and pathways; fire effects; impacts, mitigation, and rehabilitation of disturbed sites; soil-whitebark pine relationships; inventory of status and location of whitebark pine stands; classification in California; knowledge of regeneration techniques; development of whitebark pine resistant to white pine blister rust; and a need to address management of the entire ecosystem.

QUESTION 3

What management direction has your Forest taken in regard to whitebark pine?

A. Active timber management
B. Nonintervention
C. Monitoring
D. Prescribed fire
E. Other

As was expected, none of the respondents was presently doing active timber management within these ecosystems, primarily because these lands are mostly classified as unsuitable for timber production or are within wilderness and are not included in Forest Plan timber bases. However, some activity has occurred—one timber sale in the last 20 years was reported for the Beaverhead National Forest in a whitebark pine habitat type. Other Forests reported sales in adjoining habitat types, in particular, those within the subalpine fir/grouse whortleberry habitat type (whitebark pine phase).

Eighty-two percent reported nonintervention or passive management as the type of direction taken by their Forests.

Thirteen percent responded that their Forest's management direction included monitoring. The Gallatin National Forest was doing "premonitoring" or a basic characterization of these ecosystems. This brings up the important point that one must know what there is and where it is before actual monitoring can take place. Other Forests indicated that whitebark pine types are monitored during insect and disease surveys.

Five percent responded that prescribed fire was part of their management direction. Although not specifically addressed by a question, prescribed natural fire is one of the management prescriptions for many wilderness areas.

QUESTION 4

Do you envision a need to change your Forest's current direction to meet future needs?

Ten Forests responded no change and seven indicated change was needed. Regrettably, how this direction needs to change was not asked. However, change will be dictated by the results of researchers working with resource managers and the accumulation of better knowledge on these ecosystems.

CONCLUSIONS

In the greater scheme of things, little is known about the complex relationships and interactions involved in whitebark pine ecosystems, or of those considered to be ecological counterparts. Only recently have we begun to acquire ecological knowledge on whitebark pine itself. It should be obvious from this symposium that whitebark pine does not exist independently—it is a potentially long-lived part of a complex interdependent system that has evolved amid severe environments.

It is presumptuous to assume that any success with management activities is little more than chance without the knowledge and understanding of relationships within these communities. Worldwide examples of the sensitivity of these high-elevation forests to human activities, given by Holtmeier (this proceedings) in this symposium serve as lessons for our land managers. Therefore, there is a caution—any "active" management undertaken is done with risk of less than success until better information and understanding exist. This symposium has been a step in the right direction of developing some of the necessary understanding and knowledge to better manage these complex environments on National Forest lands.

Until then, "passive" or "nonintervention" management of whitebark pine and its counterpart systems, as indicated by 82 percent of the respondents, makes sense. The exception to this regards recreation management. Here an aggressive "active" approach needs to be undertaken in moderate and high use areas if we are to preserve quality visitor experiences in these visually and ecologically sensitive areas.

One thought that this survey brought out was that all of these management concerns, like the ecosystems they arise from, are interrelated. Management of these high-mountain ecosystems must involve an integrated approach. Resource disciplines will need to work together to achieve positive results. The results of the questionnaire showed a notable difference of opinion within the same or similar disciplines. What would the results have been if an interdisciplinary group had been surveyed? This illustrates the need for better information management and increased communication between the research community and field personnel.

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Speakers answered questions from the audience following their presentations. Following are the questions and answers on this topic:

Q. (from Anonymous)—The final "pie" showing 45 percent no change (referring to Question 4), does not agree with the aggregate of your "bar" displays (referring to Question 1). Explain. How does this support your questionnaire?

A.—We believe that this contradiction is a result of pragmatism among the respondents. There are many things we do as land managers or specialists that we would like to explore, but they are not always practical with the tight budgets the Forest Service works under. This survey represents valid concerns, but what can be done about these concerns is expressed with some frustration in Question 4.

INFORMATION GAPS AND RESEARCH NEEDS FOR WHITEBARK PINE

Don G. Despain
Richard G. Krebill

ABSTRACT

Whitebark pine (Pinus albicaulis), *an attractive conifer in the upper elevation forests of western mountains, has received little scientific study compared with other conifers prized for their commercial timber properties. Its importance as a food source for grizzly bears* (Ursus arctos) *and other nongame animals and birds is now stimulating considerable interest among specialists in the Rocky Mountains. If managers also take notice, this species will become a prime candidate for increased ecological research. Considerable new information is needed and must be applied if the species is to withstand forest succession and elevated levels of bark beetles hastened by fire prevention, introduction of the devastating white pine blister rust, and potential climatic warming.*

INTRODUCTION

It is easy for researchers to assume that information gaps and research needs are synonymous terms. However, when we look outside our ivory towers we can see that they are not. Most people are not aware of the importance of whitebark pine (*Pinus albicaulis*) in the total ecosystem and many would doubt that this species is worthy of any special consideration. After all, it may be pretty, but it has little direct economic value. Before much consideration will be given to this species, a lot of people must be made aware of its special importance and its possible contributions.

Early in this conference John Mumma said we have barely scratched the surface of the knowledge we need to manage this species. The rest of the symposium bore that out. Just what do we know in relation to what we need to know when we get into a management mode? Steve Arno pointed out that more is known about the whitebark pine in the Intermountain West than in the whole rest of its range. There is a large geographic area where there is an almost total knowledge gap, and there are research opportunities everywhere.

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CLIMATIC CHANGE CHALLENGES

Cliff Martinka brought out how rising carbon dioxide levels are going to bring about a climatic change. It may already be with us. Climate has changed in the past on a continuing basis, and we have absolutely no reason to believe that the climate is going to remain static. The rate of this change is subject to some controversy, but there are indications that humans are hastening the process so that changes in the next several decades will occur at a pace previously unknown to whitebark pine.

Regeneration processes may be the first to show the effects of climatic change. Established trees may persist for some time, but when it comes time to replace those trees the site may no longer provide the needs for seedling establishment. Disturbance will eventually come along and eliminate stands. If climatic change means that whitebark pine can no longer get established on that site, are there other sites within range of the seed-dispersing Clark's nutcracker that are suitable for seedling establishment? We may not know enough about the physiological requirements of whitebark pine to successfully replace natural seed dispersal with artificial planting and probably do not have the will to do so. If the climate is warming, as many suspect, there will be very little space for new forests on the tops of mountains above our current subalpine forests where whitebark pine prevails. Kate Kendall indicated that there already are many places where no regeneration takes place. The trees are being killed by bark beetles, fire, or white pine blister rust, but small trees are not becoming established to take their place. Are we seeing the first indication of climatic change or the results of disease or disturbance? Research is needed to determine which is the case.

If the climate that is now in Yellowstone moves northward to Glacier National Park, perhaps the Yellowstone whitebark pine blister rust problem may be solved, but Yellowstone managers will then be faced with another difficult decision if they decide to preserve ecosystems that prevailed when the Park was established, especially if its climate becomes more steppelike. It is extremely expensive, if not impossible, to get trees to grow where the site does not provide all the needs of the species. To begin to assess the problem, we have to learn much more about whitebark pine's environment, where it is and where it is going. We need to know not only the physiological needs of whitebark pine, but also its genetic peculiarities and silvicultural problems.

ADDITIONAL NEEDS

Although we personally consider whitebark pine's adaptability to climatic change as the most challenging research need that now exists, we came up with a list of additional information gaps and research needs that were mentioned during the symposium and things we thought of on our own. The remainder of this paper is a discussion of that list.

We need a series of permanent plots set up across the elevational and latitudinal range where these plots can act as monitors. They need to be set up for long time periods because we are dealing with a species that has a long life and where changes normally happen slowly. Not only do we need these plots but we need an information storage and retrieval mechanism that will keep these data safe and retrievable for future generations of researchers. We must be able to go back every 5 or 10 years, get access to the previous information for interpretation, and add additional new data. Any individual researcher may only need to access the information once or twice in a whole career; so a desk drawer will not work. We need permanent plots and we need to have long-term, multiuser access to the data.

We need to know the tolerance limits and optima for such factors as soil moisture, soil nutrients, and temperature, and how they relate to climatic factors and to the different growth stages of whitebark pine. It is not enough to know how a tree responds to its environment. We must know how a seedling, a sapling, a young tree, and an old tree respond to the environment. The response to environmental factors is not the same throughout the life of the tree.

What is the role of summer rain as well as spring and fall frosts? It is interesting that Tad Weaver reported that the minimum temperature of both the lower limit and the upper limit are about the same. What does this mean to the plant? Does it mean anything at all? Is this important to whitebark pine or to its competitors?

What are the site requirements of whitebark pine and its associates? We need to extend the kind of work done by Dave Mattson on Mount Washburn to see what the site characteristics are in other parts of the whitebark range. How much sunlight do they need? How much food can they make per packet of sunlight available to them? What is their real shade tolerance? How warm can they get before respiration is greater than photosynthesis? Are there any photoperiodic responses that need consideration, especially if latitudinal movements are to be carried out for management purposes?

We need to know more about tolerance to pollution and tolerance to diseases. What is the genetic variability of the species and local populations in relation to these factors? Are the different stages of growth equally susceptible to fungi and insects?

Is there enough natural resistance to white pine blister rust for natural selection to maintain the species throughout its range? Can resistance be stimulated through tree improvement and more intensive management programs? Can mountain pine beetle mortality be avoided through use of semiochemical repellents such as verbenone?

Our friend from Germany, Dr. Holtmeier, talked about snow-holding capacity of whitebark pine stands. Just what is this capacity and how does it affect the hydrology of the streams of our ecosystems and the safety of the visiting public? This brings up another major information gap. We need to find out what our European counterparts have already discovered about similar species in their countries. Is it time for a review paper or book on the ecology and management of stone pines?

How to determine the factors that control the periodicity of seed production is a frequently mentioned problem needing work. What is the interaction between periodicity of seed production and the seed predator load? How dependent on whitebark pine are the Clark's nutcrackers? How do their populations change in relation to the production of whitebark pine seeds? Do the prevailing theories about minimum viable populations have any application to whitebark pines? We need to amplify and extend the studies on other seed predators reported at this symposium.

We need to know a lot more about the relationship of this species to fire. How do fires burn through these stands, and how fast do they return to the burned area? Are the seeds already in the stand in caches safely below the depth of the lethal temperatures?

BROADER QUESTIONS

These are all very practical questions, but sometimes important research questions seem to be quite impractical, although they are not.

Just where did this species originate? Where did the stone pines in general originate? What are their migration routes? Maybe there is no immediate practical application for answers to these questions, but we may find some piece of information that is vitally important that we had not thought of before. Or perhaps other questions will arise from the knowledge gained that will be crucial for future management of whitebark pine.

What are the DNA relationships among members of the stone pine group? This gets into microbiology and microchemistry. The answers will be helpful in knowing how these taxa are related and how much information can be transferred from studies of other stone pines.

How can we differentiate between young limber pine (*Pinus flexilis*) and whitebark pine? Can some difference be found in the pollens of the two species that will allow us to separate them in the pollen records? This information will be needed before we can successfully look into the migration of the species in past times and be able to better predict speed of future migration. This involves interaction with the nutcrackers and is important relative to climatic change.

What is the mechanism guarding against hybridization? Apparently none of the stone pines hybridize with any others. Similar as they are morphologically, they do not mix genetically. What are the barriers to gene flow and can we use these barriers to our advantage? Or can we break down or bypass these barriers to our advantage? Can barriers be transferred to other species that we may want to keep genetically pure?

Are there ecotypes, and do these ecotypes have the genetic barriers against each other as indicated by the studies of the three different populations in California? What would be the advantages and disadvantages of such barriers? The answers to these questions may be the difference between success and failure in any management scheme that involves transplanting from one region to another.

Do we have any estimate of the number of seeds cached in unsuitable places? A single clump of whitebark pine grows in a meadow. Is that the only cache, or were seeds cached all over the meadow and that is the only place that could successfully produce full-grown whitebark pine?

So far we have mainly discussed the information needs of a single species, whitebark pine, and yet its fate is intimately intertwined with the ecology and behavior of its associates. Especially, we need to know a lot more about the Clark's nutcracker, which is so important to regeneration of whitebark pine.

Little is known about how far nutcrackers carry their seeds, what kind of sites they select, and whether they can be counted on to carry the seeds to those sites that will become whitebark pine sites under new climatic conditions. What are the competitive relationships between whitebark pine and other tree species with which it grows? How does it interact with the herbaceous members of its community?

We need improved landscape level successional models to better understand the complex parameters affecting whitebark pine ecosystems. Future planning and operational decisions will soon be made in a Geographic Information System (GIS) context, so it is timely to move whitebark pine into the computer age. This will require additional research, development of models and systems, and careful testing and improvement.

Finally, a field of research that was not represented at this symposium needs mention. We heard from no archeologists or anthropologists. The pine seeds are an important food source for bear and the bear was brother to the Native Americans. We know pinyons and limber pine were used extensively by earlier cultures.

Did aboriginal populations in this area use whitebark pine seeds? They certainly have more food value than many of the grasses they used for food.

ON WITH THE QUEST

To sum up, this has been a good symposium. Much research has been reported, and exciting discussions were generated. One mark of good research is that it asks more questions than it answers. Such has been the case here. As we go on in our quest for more answers about whitebark pine many, many more questions will surface. Along the way let us keep in mind the knowledge gaps that exist in the minds of the managers, the public, and the decision makers and make sure there is easy access to all the information generated by research.

WHITEBARK PINE SYMPOSIUM HIGHLIGHTS

R. G. Krebill

ABSTRACT

A highly significant step was taken in the assembly of a broad cross section of land managers, scientists, and other experts in this first formal symposium devoted to the whitebark pine ecosystem. Information sharing among the many experts, on and off the agenda, increased our understanding and appreciation of whitebark pine ecology, and should lead to improved research and management of this unique and important high-mountain resource.

THE ECOSYSTEM

The whitebark pine ecosystem has long occupied the northern mountains of the Western United States and Canada. Occurring in the harsh environment near the upper timberline, the ecosystem has amazing natural resilience. The pollen record in south Yellowstone indicates a waxing and waning in inverse synchrony with glacial advances and retreats of the past 100,000 or more years. Besides changes in climate and churning of substrate by frosts and glaciers, whitebark pine forests have evolved under such influences as heavy winter snow cover, violent wind, avalanches, bark beetles, and wildfire. With natural disturbance, whitebark pine has a slight advantage over competing tree species to maintain dominance in the upper elevations of many of the high western mountains.

Whitebark pine is estimated to be present in about 8 percent of the total forests of the National Forest System, and is more prevalent at higher elevations in the northern Rocky Mountains, where for instance, it is a significant component of about 18 percent of Yellowstone National Park. The whitebark pine ecosystem is especially prized for its natural beauty and recreation potential, its importance as wildlife habitat, its value in protecting high-mountain watersheds, and for its biodiversity and intriguing natural processes.

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MANY CONCERNS

But is this precious whitebark pine resource imperiled by increasing human influence in high-mountain ecosystems? A little more than 100 years ago, prospecting brought an influx of people into many of our mountain areas. Direct losses of whitebark ecosystems to soil movement were minimal, but as indicated for the Butte vicinity, harvesting of its trees for fuelwood, charcoal, and mine timbers was heavy over fairly broad areas. The high mountains were soon seen as a valuable source of forage, and uncontrolled grazing for a few decades led to serious impacts on meadow and understory vegetation, from which many sites have still not fully recovered in spite of several decades of improved range management.

Even more serious is the threat by white pine blister rust, which was inadvertently introduced early in this century. Unfortunately, whitebark pine is perhaps its most susceptible host and many stands in northwestern Montana, northern Idaho, and British Columbia have already been nearly eliminated. Unlike the situation with mountain pine beetle, whitebark pine had not coevolved with the blister rust pathogen. If that is not enough cause for concern, we also have learned that effective fire control in the current century is allowing forest succession to favor subalpine fir and Engelmann spruce on many sites formerly dominated by whitebark pine.

It is also somewhat disturbing to compare our past century of impact on high-mountain whitebark pine with the more subtle but enduring impacts of wood gathering and conversion of stone pine forests for grazing in Eurasia. In comparison, our North American whitebark pine forests hardly appear impacted, but as we learned in this symposium, they are. And we have only been at it for about a century; the Eurasian mountain forests have accumulated the impacts of many millenia of use. Let us not forget the potential for subtle effects to accumulate into major changes over long periods of time, and give adequate weight to time in our cumulative effects analyses.

Recent concern was also expressed over the increased recreation use in our high-mountain forests over the last few decades, and particularly the exploitation of scarce wood for campfires. Is this different than what was done by many of our ancestors in Eurasia? Other concerns were voiced during the symposium over the ever increasing numbers of roads, transmission lines, electronic sites, and resorts placed in high-mountain areas. Concern also was expressed about the potential for human activity to produce harmful air pollution, and to hasten global climate change to the detriment of high-mountain forests.

UNDERSTANDING IS KEY

On the positive side, interest in whitebark pine ecosystems has risen dramatically in the 1980's, in part inspired by the surprising finding that whitebark pine seeds are important to the vitality of grizzly bear populations in the Yellowstone area. With this interest have come several studies into the ecology of whitebark pine that have greatly raised our level of understanding of the functioning of whitebark pine ecosystems and the strong reliance of many of its species upon one another. Understanding these relations is a key ingredient to prescribing management that will perpetuate these vulnerable high-mountain forest ecosystems.

Some of this symposium's information highlights to me were:

- The strong evidence that whitebark pine almost totally relies on the Clark's nutcracker for natural regeneration through the bird's seed caching behavior. With an ability to carry up to 150 seeds in its throat pouch, and to disseminate seed up to 15 to 20 km, it is little wonder that this tree has persisted through the millenia in spite of disruptions as severe as glacial activity and major fires.
- The classic interdependence of numerous species in whitebark pine ecosystems. Especially interesting are the relations of bird to tree to red squirrel to bear, and the importance of whitebark pine ecosystems as seasonal range for elk and other wildlife, the importance of these areas as a source for water for fish and other downstream users, and the interactions of mountain pine beetle in both lodgepole and whitebark pine forests.
- The report that whitebark pine seeds have been documented as bear food for at least 15 years.
- The recent research findings clarifying the requirements for whitebark pine seed germination and seedling establishment.
- The wide range of soils and geological formations upon which whitebark ecosystems prevail.
- The capability of whitebark pine to extend itself through layering.
- The use of shape of trees near timberline to quantify mean wind speeds and snow depths.
- The finding that whitebark pine often dominates in upper slope areas that are a little warmer than lower slopes where fir and spruce prevail.
- The importance of fire in maintaining seral whitebark pine forests.
- The evidence of widespread loss of whitebark pine to white pine blister rust in the Northern Rocky Mountains.
- The recent development of a predictive process model for whitebark pine forests.

Thanks to a dedicated group of scientists, specialists, and generalists, a mild revolution obviously has been under way to improve our understanding of whitebark pine ecosystems.

Those who remained for the postsymposium field trip to see whitebark pine firsthand were in luck (fig. 1). As they arrived at Big Sky, the clouds dissipated and the party was treated to the bright splendor of the high mountains at their best. Many of the ecological marvels discussed during the symposium were close at hand for group and individual interpretation. All in all, the field trip was a most fitting climax to an outstanding symposium.

Figure 1—Professor Tad Weaver (right) in his natural habitat, surrounded by interested "students" in a whitebark pine forest during the symposium field trip.

SYMPOSIUM CRITIQUE

My critique of the symposium is that the arrangements, hospitality, and orchestration of the program were superb; the agenda provided exceptionally good coverage of an impressive range of topics; the quality of presentations was variable but always interesting; illustrations were excellent but often used to excess (in part representing

the photographic appeal of the whitebark pine resource); and the depth of scientific inquiry was generally shallow, indicating a need for much additional research.

Although it is clear that we do not know all there is to know, surely we are now much better equipped to successfully manage this outstanding high-mountain resource. The best part of the symposium was its many participants who represented a broad range of expertise and interests, yet were always so free to enter into discussion and share ideas.

Comments on the highlights of the symposium were solicited from all participants. Following are excerpts from their comments, slightly edited to follow the phrase, "The highlights of the symposium were . . . "

(from Richard Baker) " . . . the diversity of papers presented, and learning more about the whitebark pine ecosystem and about the ecology of whitebark pine."

(from Ray Brown) " . . . learning the MSU plans to organize a High-Elevation Studies Program, a super, vitally important idea; learning so much about the basic biology and its application to management of the whitebark pine life-zone; and meeting so many vital, intelligent young people (and some old ones) who are so interested in improving our understanding of high-elevation ecosystems."

(from David Charlet) " . . . meeting and speaking with researchers from diverse fields connected with the common theme of high-altitude ecology; the presentations, allowing me to feel very informed on the current state of knowledge; the dissipation of the feeling of isolation in my concerns, perceptions, and research . . . coupled with a renewed hope that we can coordinate our efforts and make a genuine impact reversing the destructive path of the past; and the feeling of being taken care of in fine style by the coordinators of this symposium."

(from Jim Chew) " . . . any presentation that actually had some quantification to it, as many were no more than nice slides and generalizations."

(from Richard Clark) " . . . description of whitebark ecosystem baselines; overview of some theories of management; a look at this ecosystem as a unit of the wilderness system; and the emphasis on the whitebark ecosystem as a unique system with value."

(from Doug Eggers) " . . . the opportunity to hear about what others have observed and documented concerning whitebark pine; the items that helped in my understanding and perspective; for example, the observations on grazing, especially heavy grazing in past years and its effects on today's whitebark pine forests."

(from Phil Farnes) " . . . meeting people having knowledge or doing research in whitebark ecosystems, and the good descriptions of the various components of whitebark pine ecosystems."

(from Sam Gilbert) " . . . the significant increase in interest in whitebark pine ecosystems in the past few years; the encouraging knowledge that we have acquired on the subject; and the excellent visual aids."

(from Ken Gibson) " . . . bringing together of the amount of knowledge on whitebark pine ecosystems; the focus on knowledge gaps; seeing that research is going on, and has been for some time; and the awareness of the uniqueness of whitebark pine ecosystems and the need for special management for these ecosystems."

(from Harvey Good) " . . . the Clark's nutcracker relationship with whitebark pine, the red squirrel ties to grizzly bear and whitebark pine, the genetic aspects of whitebark pine, and the allozyme relationships within strains of *Pinus albicaulis* and other pines."

(from Ron Hamilton) " . . . the assemblage of participants in general; the diversity of the people participating and the good contacts made for future reference; the holistic perspective of presentations; and the somewhat overlooked need to better understand ties between adjacent ecosystems (for example, mountain pine beetle/lodgepole pine/whitebark pine interactions), so that we can improve future management."

(from Harry Hutchins) " . . . animal interactions and the world perspective of the stone pines, especially the unique and interesting perspectives of Jack Ives and Herr Holtmeier."

(from Fredrich-Karl Holtmeier) " . . . the symposium in total—the many different aspects under which the whitebark pine ecosystems have been considered; the papers dealing with the mutual relationships between whitebark pine and animals, and the useful information from all papers presented. It has been an interesting and successful meeting; congratulations and thanks to all who were involved in its preparation and organization."

(from Peter Kolb) " . . . the diversity of subjects covered and the qualifications of most of the speakers."

(from Jack Ives) " . . . the realization of the intricate network—birds, animals, insects, man, fire—involved in whitebark pine ecosystems."

(from James Jacobs) " . . . information gained from climate data and lack of available weather stations; stand dynamics including relations between densities, circumference, basal area, and age; and animal/plant interrelationships."

(from Kate Kendall) " . . . the focus of attention on this resource, which it is to be hoped, will translate into more management concern; the updating of ongoing work in a range of disciplines, and the opportunity to air my concern about declines in whitebark pine to an appropriate audience."

SEEING WHITEBARK PINE IN A NORTHERN ROCKY MOUNTAIN LANDSCAPE: NOTES FOR A FIELD TRIP

T. Weaver

ABSTRACT

The changing role of whitebark pine (Pinus albicaulis) *along an altitudinal gradient typical of the Northern Rocky Mountains (USA) can be seen from the gondolas at the "Big Sky" resort near Bozeman, MT. Whitebark pine appears mostly as seedlings in the lowest zone (7,500 to 8,500 ft), becomes increasingly important in the canopy between 8,400 and 8,900 ft, assumes climax dominance in the woodland zone (8,900 to 9,300 ft), and maintains that dominance to treeline. On this gradient the mature tree's growth form changes from tall-lyrate, to shorter-spherical, to krummholz. The tree is seral in the lowest zones; frequent fires exclude it from canopies in the lowest zone, while low fire frequency gives it subclimax status higher (8,400 to 8,900 ft) in the zone dominated by subalpine fir* (Abies lasiocarpa) *at climax. Above 8,900 ft, whitebark dominates woodlands (formed, probably, when subalpine fir is excluded by cold) and krummholz (due, probably, to winter desiccation). Mountain pine beetles* (Dendroctonus ponderosae) *have killed much of the lodgepole* (P. contorta) *and whitebark pine in the area, and whitebark groves tend to be ringed with dead trees because the especially vigorous trees at grove edges are most susceptible. Cirque bowls on Lone Mountain demonstrate an inverted timberline at which conifers disappear downward, probably due to spring frosts.*

INTRODUCTION

The "Big Sky" a popular resort 50 mi south of Bozeman, MT, is an excellent site for an introduction to whitebark pine (*Pinus albicaulis*) in its Northern Rocky Mountain setting. One sees, there, altitudinal zones demonstrating all its major roles: in a relatively low-altitude band the tree is seral to subalpine fir (*Abies lasiocarpa*), in a middle band whitebark dominates woodlands, and in a higher band it forms krummholz. And the whitebark zone is accessible on a year-round basis—thanks to paved roads leading to the resort and gondolas that traverse the forest zone during both winter and summer seasons (phone 406-995-4211 for information).

This note summarizes observations made by participants in a whitebark pine symposium (March 31, 1989) and can guide professionals visiting the area at later dates. Its three sections describe the study area, vegetation phenomena best seen from the gondola, and landscape phenomena best seen from a road connecting the tops of the north (#1) and south (#2) gondolas. Readers guiding themselves through the area with these notes can use the gondola pylon altitudes (table 1) for orientation. They can find more detailed discussion of most phenomena discussed here in chapters of this proceedings on whitebark pine forests, cited here by author.

PREVIEW OF THE STUDY AREA

The "Big Sky" gondolas rise from 7,500 to 9,200 ft, and chairlifts proceed to 9,800 ft. As they rise, both gondolas cross a gradient in which the soils become rockier, the climate becomes cooler, stand-replacing fires become more infrequent, and a lodgepole pine-subalpine fir (*Pinus contorta-Abies lasiocarpa*) forest mosaic is replaced in turn by open woodlands of whitebark pine and a mosaic of krummholz and alpine grassland.

Geology

Lone Mountain is a conical peak (11,166 ft) built from clay-rich sedimentary beds of the quaternary. The peak dominates its landscape because, while the unconsolidated sediments around it have eroded away, its mass was baked to slate and supported by andesitic intrusions. The quaternary deposits are underlain by mesozoic and paleozoic sediments and precambrian metamorphics exposed at the edges of the Jack Creek/West Fork/Porcupine syncline to the north and south (Tysdal and others 1986).

Substrate

The trees at highest altitude grow on bedrock outcrops, while grassy areas between the spurs occupy substrates deposited by gravity (colluvium), glaciers (till), and water (alluvium). Lower on the slopes (under the gondolas), substrates are less often bedrock and more often glacial or alluvial (Hansen-Bristow and others, this proceedings).

Climate

Showers of more than 0.01 inch fall on about half of the winter days and a third of the summer days. Amounts

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Table 1—Distribution of current forest types, climax forest types, and environmental types under the "Big Sky" gondolas

Altitude	Current vegetation[1]	Climax vegetation[2]	South gondola	North gondola
Ft			*Pylon #*	*Pylon #*
9,200	WB/whortleberry	WB/whortleberry	lift top	
9,000	WB/whortleberry	WB/whortleberry		lift top
8,900	WB/whortleberry	WB/whortleberry	25	21
8,400-8,900	SAF, WB, LPP, wb[3]	SAF/whortleberry		
8,400	LPP/whortleberry	SAF/whortleberry	17	15
7,500	LPP/whortleberry	SAF/whortleberry	base of lift	base of lift

[1]Plants mentioned here are whitebark pine (WB, *Pinus albicaulis*), lodgepole pine (LPP, *Pinus contorta*), subalpine fir (SAF, *Abies lasiocarpa*), and grouse whortleberry (wb, *Vaccinium scoparium)*.

[2]Forest environmental types are classified and described by Daubenmire and Daubenmire (1968) and Pfister and others (1977). They are named for the climax vegetation that occupies them. The name consists of the name of the dominant overstory tree, a slash, and the dominant understory plant. The current vegetation of a site of one environmental type can be climax or seral.

[3]While low-altitude subalpine fir sites are dominated by lodgepole, absence of fire in the highest subalpine fir sites allows species representing later seral stages to grow into the overstory.

deposited are likely similar all along the gondola transect, with an average of 3 inches per month in the winter and less than an inch per month in the summer. Average maximum temperatures in the woodland zone just below timberline are probably 20 to 25 °F in January and 65 to 70 °F in July. Average minimum temperatures in the woodland zone are likely 5 to 10 °F in January and 40 °F in July (Weaver, this proceedings).

Fire

Despite similar start frequencies, fire is relatively frequent at the altitude of the gondola base (because it spreads easily in an undissected landscape) and relatively rare in the ridged province at the altitude of the gondola top.

Climax Vegetation and Environmental Types

If it were climax—undisturbed for hundreds of years—the vegetation beneath the gondolas would range from subalpine fir forests (from the gondola base through the current canopy transition zone, 7,500 to 8,500 ft), to a whitebark pine woodland (8,900 to 9,200 ft) at the top (table 1). Near the gondola top (8,900 to 9,300 ft) climax vegetation alternates between whitebark pine woodland and meadow with the forest occupying bedrock ridge sites and the meadow occupying colluvial-alluvial valley sites as well as the south-facing slopes of Lone Mountain. From chairlifts above the gondolas one sees that a mosaic of krummholz and "alpine grassland" occupies stable areas on ridges, while cliffs and excessively drained talus intervene. Ecologists use climax vegetation as an indicator of environmental type (Daubenmire and Daubenmire 1968; Pfister and others 1977).

Seral Vegetation

Because fire is relatively frequent at the altitude of the gondola base, trees that invade after fire (lodgepole pine) often replace climax trees (subalpine fir) there. In contrast, fire is relatively rare in the ridged province at altitudes near the gondola top so the forests there are subclimax and open woodlands are near climax.

OBSERVING THE FOREST ZONE FROM THE GONDOLAS

The gondolas traverse two environmental zones occupied by three vegetation types. Most of the vegetation of the subalpine fir zone (7,500 to 8,900 ft) is seral. The whitebark woodlands (8,900 to 9,300 ft) are near climax. Within a few hundred feet above the gondola tops krummholz dominates the arboreal vegetation. The following paragraphs point out details best seen from the south gondola (#2).

The ski runs are very early seral with bare ground being invaded, below 8,950 ft, by lodgepole pine and, especially on north slopes and cold draw bottoms, Engelmann spruce (*Picea engelmannii*). While whitebark seedlings are common in forests all along the transect, there are essentially none in the ski runs.

In the lowest zone (7,500 to 8,400 ft) most current overstories are dominated by lodgepole pine, which colonized after fires of different dates.

1. Patches containing young (thinner) lodgepoles indicate recent fire, while those containing older (thicker) trees indicate more ancient fires. Lodgepole is recognizable by 2-inch needles in bundles of two and numerous compact, closed cones. While both subalpine fir and whitebark pine seedlings appear in the understory, fires of the past have removed the stands before they could occupy the overstory.
2. The oldest—longest unburned—patches occupy narrower valleys and steep north-facing slopes; their overstories contain subalpine fir, spruce, and old lodgepole pines. The subalpine firs have very pointed tops, the spruce have broader tops often with open cones, and both have flat needles less than 1 inch long.
3. If you look at distant slopes, especially from the bottom and top of the gondola, you will see patches with different textures: the finest textures are young stands, coarser textures indicate older stands, and the coarsest and most ragged-looking stands approach the climax condition.

4. If fire were excluded from this zone, forests in the area would be dominated by subalpine fir in the overstory and grouse whortleberry (*Vaccinium scoparium*) in the understory.

The middle zone (8,400 to 8,900 ft) is covered by relatively old subclimax forests because fires have been much less frequent in it.

1. Pines and pointed-topped subalpine fir are common in the overstory. Broader-topped spruce are relatively uncommon, except in draws.
2. At the lower edge of the middle zone the overstory pine is lodgepole. At the top edge, the overstory pine is whitebark. The two pines can be distinguished by their cones: lodgepoles bear many small, closed cones, while whitebarks bear a few 2- to 4-inch cones in the summer—or, in winter, no cones. While one usually associates the "lyrate" form with whitebark, the branches of some lodgepoles growing in this part of the gradient also fan upward, both here and in other areas.
3. The seral nature of the middle-altitude pines is seen from the fact that, while subalpine fir and spruce continue to thrive in the older stands of this zone, the pines are dying, and were doing so even prior to the recent bark-beetle epidemic.

Higher forests (8,900 ft to timberline) are dominated by whitebark pine.

1. Whitebark pine is climax here, apparently because the physical environment excludes trees that outcompete it in the two lower zones (Arno and Weaver, this proceedings).
2. While the whitebark pines were usually single stemmed in lower forests, many are either multistemmed or clumped here. This clumping derives, in part, from the fact that most were planted by Clark's nutcracker (*Nucifraga columbiana*), a bird which caches the seeds in groups of 1 to 30 for later use (Lanner, this proceedings; Tomback, this proceedings) and is secondarily increased by the tree's tendency to branch at its base (Weaver and Jacobs, this proceedings). I speculate that the increase in clumping is also due to the decrease in competition from closed forests to open woodlands.
3. The shallow structural roots of whitebark pine can be seen on overturned stumps and in cuts along the road between the tops of gondolas #1 and #2.
4. The white bark of the pine has a reddish tinge in winter. Does anthocyanin protect the bark chlorophyll, as it does the chlorophyll in many spring leaves?
5. Nonforest vegetation above 8,900 ft consists of alpine grassland and tundra interfingering characteristically with the subalpine forest (Arno and Weaver, this proceedings).

OBSERVING "BIG SKY" LANDSCAPE ECOLOGY

From the road between the tops of gondolas #1 and #2, one can review the position of whitebark pine forests in a landscape typical of the Northern Rocky Mountains.

Erosion bares steep rock at high altitude and deposition rounds lower slopes and levels valley bottoms. The top of the north gondola (#1) lies at the base of one of the most spectacular glacial cirques in the area. In the bottom of the cirque, just above the top of the north gondola, is a rock glacier, an actively moving mass of rock and ice which models the glacier that originally filled the bowl. The buildings at the base of the gondolas are built on till deposited by the large glacier, which flowed from the cirque during the pleistocene.

The vegetation zones in the high-mountain landscape can be conceived of as more-or-less horizontal zones, including, from the top down:

1. An upper forest-free zone dominated by rock outcrops, talus slopes, and grassy tundra.
2. A zone in which forests are interspersed with nonforests. Whitebark pine forests occupy the rocky ridges. The ridges provide a stable, relatively fire-free site suitable for pine growth. The valleys between may be cleared by avalanches or cold air draining into them from above.
3. The whitebark woodland zone begins in the ridge and valley zone and may extend slightly below it (approximately 8,800 ft and above).
4. The zone in which whitebark pine is codominant with subalpine fir late in succession is detectable from its uneven "ragged" look. The existence of this zone also depends on a low fire frequency attributable to the valley-ridge structure in the landscape (approximately 8,400 to 8,900 ft).
5. Below 8,400 ft the valley broadens so that the spread of fire is less inhibited by the valley-ridge structure. As a result, one sees coarse-grained patches of relatively old trees that burned long ago interspersed with fine-grained patches of young trees on sites that were more recently burned.
6. At successively lower altitudes below the gondola base (7,500 ft), one sees zones of Douglas-fir (*Pseudotsuga menziesii*) and grass-shrubland never occupied by whitebark pine.

Changes in substrate may also affect whitebark distribution. While the whitebark trees near timberline on Lone Mountain are growing on slates, many sandstones, and most of the precambrian metamorphics, whitebark pine avoids limestone in our area (Weaver and Dale 1974) and is generally replaced on limestone outcrops by limber pine (*Pinus flexilis*), subalpine fir, or Douglas-fir.

Many of the pines seen from the gondola are dead. Most of the dead trees were killed by the pine bark beetle (*Dendroctonus ponderosae*) (Bartos and Gibson, this proceedings).

1. A survey of the valley below demonstrates the breadth of this attack.
2. While many of the trees with a phloem layer thick enough to support the beetle (larger diameter trees) are dead, thinner trees often escape beetle attack. I point to two resultant phenomena:

   a. Elimination of lodgepole (thick trees) from the overstory probably favors whitebark pine (thin trees) in the understory and may allow whitebark pine to dominate sites that would otherwise have succeeded more rapidly to subalpine fir.

b. Due to lesser competition, trees at the edge of groves are larger than those in the center. As a result they have thicker phloem, are more readily attacked by the bark beetle, and die. I attribute the fringe of dead trees around the grove north of the north gondola (#1) to this phenomenon.

Near timberline, trees are absent from interridge areas because of avalanches or frost damage due to cold-air drainage. I offer the meadow in the lower cirque bowl (just above the top of the north gondola) as an example of exclusion of trees by cold-air drainage. Three points favor this hypothesis:

1. Cold air is known to pond in such depressions.
2. Conifers are known to "frost deharden" in spring, so heavy frost might eliminate them; such damage was observed on 3- to 5-year-old seedlings in the spring of 1988. Frost resistance apparently declines from whitebark pine > spruce > fir ≥ lodgepole pine.
3. The cold-air pond is ringed by bands of progressively older trees. Due to every-year frosts, no trees exist on the pond bottom (meadow center). A band of small trees (1 m high and buried by snow in winter) occupy a "shoreline" that hasn't experienced killing frost in 10 years or so, but these are likely to be killed eventually. A higher "shoreline" represents the "highest water" (= deepest ponding) that has occurred in 20 to 40 years; the tops of these trees may have emerged from the cold-air pond and, if so, they may grow crowns with normal tops and frost-pruned bottoms. The largest (mostly beetle-killed) trees occupy an area that is always above the cold-air pond's surface.

Most alternate hypotheses put forward to explain the distribution of trees in this bowl can be dismissed:

1. Avalanche damage seems unlikely, because existing trees show no evidence of snow movement and because alluvial-aeolian soil in the basin bottom lacks avalanche-borne rocks.
2. While colder air ponds in the basin in winter than in the spring, trees are adequately hardened against frost in winter (Tranquillini 1979).
3. Though it is in a depression, most if not all of the meadow site is too well-drained to allow water drowning.
4. Absence of flagging on existing trees discounts the possibility of wind-induced desiccation damage.

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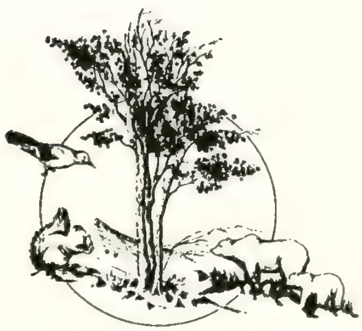
POSTER PAPERS

Synopses of 14 Posters Shown at the Symposium



POSTFIRE VEGETATIVE RESPONSE IN A WHITEBARK PINE COMMUNITY, BOB MARSHALL WILDERNESS, MONTANA

Maria Ash and Richard J. Lasko

On June 28, 1985, lightning ignited three small fires on the ridge just west of Charlotte Peak in the Bob Marshall Wilderness, MT. These three fires were managed collectively as the Charlotte Peak Prescribed Fire and were part of a program to restore fire to the Bob Marshall Ecosystem. The Charlotte Peak fire burned nearly 5,400 acres before it was extinguished by heavy rains in late July and early August.

A field study was initiated in the summer of 1986 for the purpose of measuring vegetative response to fire in several different community types. A plot in a whitebark pine (*Pinus albicaulis*) community type was located near the point of ignition, just below the main ridgeline west of Charlotte Peak (Plot 114).

The criteria for placing this plot were that the preburn community was a mature stand dominated by *Pinus albicaulis* and was completely consumed by fire. The plot was permanently marked and has been remeasured annually since the fire (1986-1988). The study site is located at an elevation of 7,320 ft with an easterly aspect on a 40 percent slope. The Montana Forest Habitat Type most closely resembles *Abies lasiocarpa/Luzula hitchcockii/Vaccinium scoparium*, though postfire determination is difficult. The preburn stand was approximately 195 years old with a mixed *Pinus albicaulis* and *Abies lasiocarpa* overstory.

METHODS

Plot 114 was sampled using Ecodata Classification Sampling Methods. Species' frequencies and canopy coverages were measured within 25 microplots on a 10th-acre macroplot. Ground cover and production by life form was also measured. Tree and shrub densities were measured by age class. Other data were also taken for each species, including canopy coverage by age/size class, distribution, phenology, height, and hedging class.

RESULTS

It was observed that, even though a stand-replacing fire occurred, fire severity was low due to (1) low mineral soil (1 to 5 percent) and high litter and duff (85 to 95 percent) ground coverages, and (2) the high number of species that resprouted, including *Xerophyllum tenax*, which has a rhizome highly susceptible to severe fires. This low fire severity influenced the types of species that returned. In plot 114, 53 percent of the species found after the fire resprouted from surviving roots (table 1). Six percent were onsite (residual) colonizers, plants which germinated from seeds that were in existence either in the ground or in tree crowns before the fire. Thirty-five percent were offsite colonizers, species which germinated from seeds that were brought to the plot by either animals or wind. Six percent were of unknown origin.

One of the more notable offsite colonizers was *Pinus albicaulis*. Since *Pinus albicaulis* has an indehiscent cone, it is probable that seedlings were established from Clark's nutcracker seed caching. This most likely occurred in 1987, since it was not until the third year (1988) that any conifer seedlings were noted (densities in 1986, 1987, and 1988 were 0, 0, and 264 seedlings per acre, respectively). It appears that cone crop production was poor in 1985 and 1986 but good enough in 1987 to provide enough seeds to explain the 1988 surge in *Pinus albicaulis* seedlings. This was also true for *Abies lasiocarpa*, but since its seed dispersal mechanism is by wind from the nearest unburned area it appeared in much lower densities.

Two other species of particular significance are *Epilobium angustifolium* and *Carex rossii*. *Epilobium angustifolium*'s seeds are windblown onto the site after the fire, subsequently providing vegetative and litter cover. *Carex rossii* usually does not occur in the prefire stand vegetatively, but does in the form of a residual seed in the ground awaiting fire to create the proper germination conditions.

Canopy cover and vegetative production showed significant increases each year (figs. 1 and 2, respectively); however, nested rooted frequency (fig. 3) did not change significantly. This is primarily due to the fact that the plants with the highest coverages and densities were resprouts, therefore not increasing in numbers of plants, only in size in later years. Most of the plants present in postburn years 1 through 3 became established in year 1 with very little colonization occurring in subsequent years. Only four new species with very little cover were recorded after year 1: *Tragopogon dubius*, *Epilobium watsonii*, *Abies lasiocarpa*, and *Pinus albicaulis*. Three species displayed a sporadic occurrence pattern, occurring in one year and not the next. This is probably due to the inability to locate every single plant on the 10th-acre plot each year. These species were *Senecio triangularis*, *Pyrola secunda*, and *Viola orbiculata*.

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Table 1—Survival strategies for plant species occurring on plot 114

Onsite colonizer	Offsite colonizer	Resprout	Unknown origin
Carex rossii	*Abies lasiocarpa*	*Menziesia ferruginea*	*Viola orbiculata*
	Pinus albicaulis	*Vaccinium globulare*	
	Epilobium angustifolium	*Vaccinium scoparium*	
	Epilobium watsonii	*Luzula hitchcockii*	
	Hieracium albiflorum	*Arnica latifolia*	
	Tragopogon dubius	*Pedicularis racemosa*	
		Pyrola secunda	
		Senecio triangularis	
		Xerophyllum tenax	

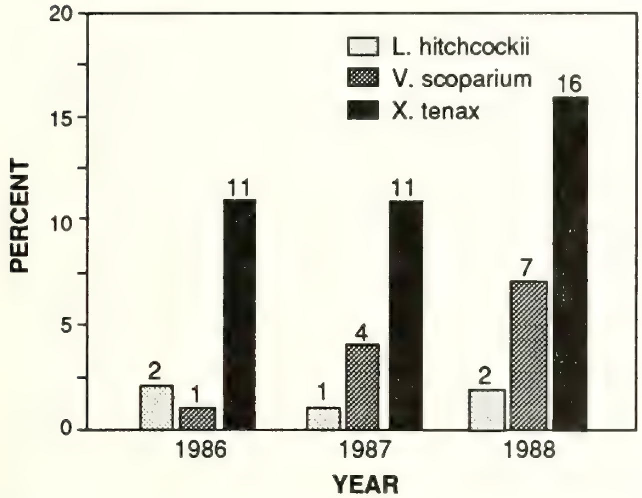

Figure 1—Canopy cover for *Luzula hitchcockii, Vaccinium scoparium*, and *Xerophyllum tenax* on plot 114 from 1986 to 1988.

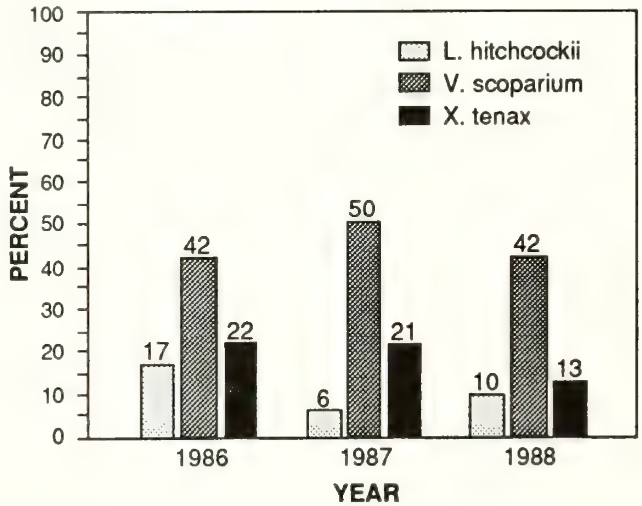

Figure 3—Nested rooted frequency for *Luzula hitchcockii, Vaccinium scoparium*, and *Xerophyllum tenax* on plot 114 from 1986 to 1988.

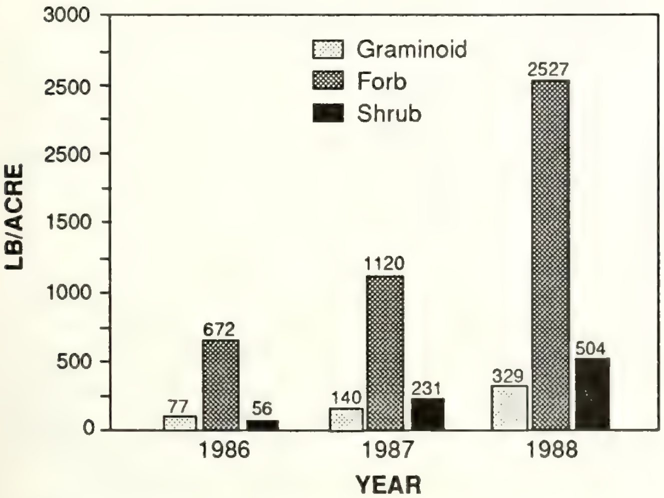

Figure 2—Total production for *Luzula hitchcockii, Vaccinium scoparium*, and *Xerophyllum tenax* on plot 114 from 1986 to 1988.

RELATIONSHIPS BETWEEN WHITEBARK PINE CONE PRODUCTION AND FALL GRIZZLY BEAR MOVEMENTS

Bonnie M. Blanchard

Whitebark pine (*Pinus albicaulis*) nuts are an important and preferred food for Yellowstone grizzly bears (*Ursus arctos horribilis*). Bears will consume these nuts to the near exclusion of other food items when they are available in sufficient quantity. High fat content of the nuts can supply the calories needed to accumulate critical fat reserves during fall in preparation for hibernation. In years of exceptional production, nuts will also be consumed in the spring and summer of the following year.

To monitor annual cone production and subsequent availability of nuts to grizzly bears, 90-m transects of 10 trees each were established in whitebark pine stands throughout the study area: nine in 1980, eight in 1987, and two in 1988. Cones were counted in July and early August before appreciable harvesting by red squirrels (*Tamiasciurus hudsonicus*) and Clark's nutcrackers (*Nucifraga columbiana*) had begun.

PRODUCTION-CONSUMPTION

Generally a significant relationship existed between cone production on transects and frequency of nuts in scats deposited during fall (September to November) when the scat sample was more than 15 (fig. 1). An exception was 1987 when the transects failed to reflect actual cone availability for two primary reasons. Cones matured approximately 2 weeks earlier than normal, probably due to favorable spring weather conditions; and transects were on the average read later than was ideal. Also, production was spotty that year and apparently poorest in xeric, pure to nearly pure whitebark pine stands. The majority of transects were in those types of stands, and cones were often noted on trees outside transects. This prompted the establishment of additional transects in mesic, mixed species stands previously unmonitored.

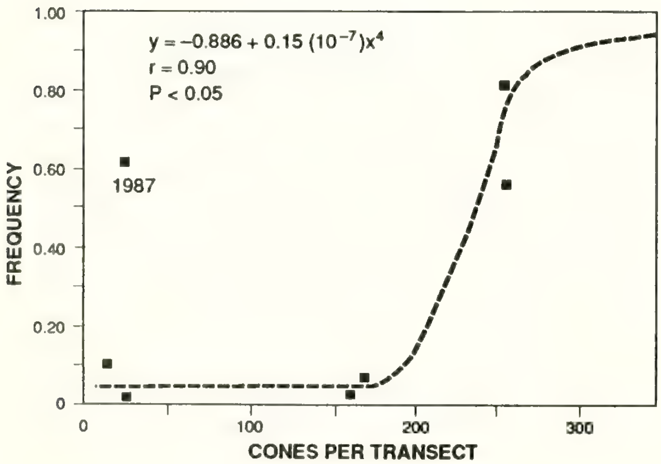

Figure 1—Relationship between mean number of cones per transect and frequency of whitebark pine nuts in fall grizzly scats.

Low amounts of nuts were consumed by grizzly bears until the mean number of cones per transect approached 200. Red squirrels and Clark's nutcrackers were probably able to consume nuts produced up to that level prior to caching of excess cones and nuts. Since grizzly bears obtained nuts primarily by raiding squirrel caches, this food source was largely unavailable until production approached 200 cones per transect. Above that level, the amount of pine nuts consumed would theoretically increase with production until bears had maximized consumption and extra cones would not be used that fall.

Maximized consumption was apparently reached in 1985 when frequency of nuts was 0.81 in all fall scats and 1.00 in October scats alone ($n = 9$). Maximum cone production on one transect was 625. A main diet item the following spring and summer was whitebark pine nuts—those remaining in caches from the fall of 1985. Frequency of nuts in scats increased from 0.06 in May ($n = 32$) to 0.29 in July ($n = 154$), compared to the 1979 to 1987 average frequency of 0.17 in May and 0.19 in July.

ALTERNATE SOURCES

When whitebark pine nuts were unavailable to grizzly bears, they sought alternate food sources, often associated with human activities. A significant correlation existed between mean number of cones produced per transect and numbers of grizzly bears trapped in management actions after August 1 for 1980 to 1986 ($r^2 = -0.815$, $p < 0.05$) (fig. 2). This correlation was less significant when data for 1987 and 1988 were added. However, data collected those 2 years were not comparable to the 1980-1986 data set. During 1987, cone production on transects did not reflect the actual production level throughout the study area for reasons discussed above, and bears were able to consume appreciable amounts of nuts. Poor cone production during 1988 was offset by alternate food items made available to bears as a direct result of the 1988 Yellowstone wildfires. Grizzly bears seeking alternate food items associated with human activities during August were drawn into burns seeking ungulate carcasses, and only one management action was recorded after October 1, 1988.

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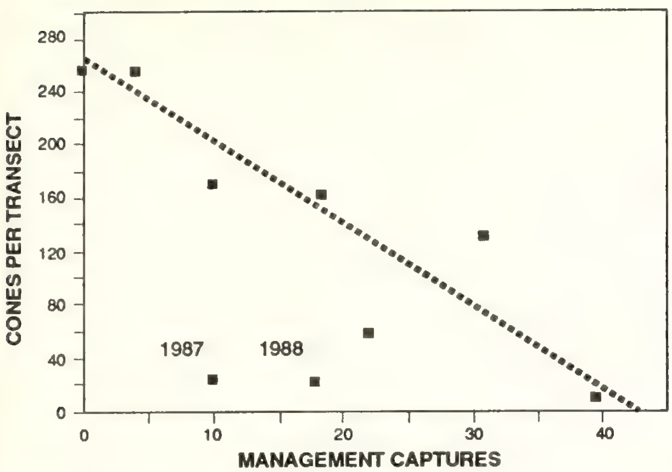

Figure 2—Relationship between mean number of cones per transect and number of management captures of grizzlies after August 1.

When cone production was low and management actions high, mortalities of female grizzly bears were also high ($r^2 = -0.691$, $p < 0.05$). This correlation was not significant when male mortalities were added. Females were possibly displaced by more-dominant males from a preferred but scarce food supply.

Whitebark pine nuts are the most important fall food of Yellowstone grizzlies, and availability of nuts influences annual feeding strategies and movement patterns. During years of low availability, numbers of grizzly/human encounters are greater, resulting management actions more numerous, and mortalities of female grizzly bears higher.

THE FIRE EFFECTS INFORMATION SYSTEM: AN AID TO WILDLAND FIRE MANAGEMENT

Anne F. Bradley

The Fire Effects Information System (FEIS), a "new generation" knowledge management tool, is designed to store and provide easy user access to state-of-the-knowledge information on the effects of fire and general ecology of plant species and communities. System software was developed in a cooperative effort between the University of Montana Computer Science Department and the Fire Effects Research Unit of the Forest Service's Intermountain Research Station.

Information is stored as text in the FEIS knowledge base and can be viewed as paragraphs on a screen by the user. The system is menu-driven and requires only minimal experience with a computer to operate. The information is organized and accessed by categories. Information on plant species, plant communities, and wildlife species is available. As an example of the organizational structure, plant species categories that may be viewed are:

Taxonomic Information
- Species Name
- Abbreviation
- Synonyms
- Common Name
- Taxonomy
- Life Form
- References

Species Distribution and Occurrence
- General Distribution
- BLM Physiographic Regions
- Kuchler Plant Associations
- SAF Cover Types
- Habitat Types and Plant Communities
- References

Botanical and Ecological Characteristics
- General Botanical Characteristics
- Raunkaier Life Form
- Regenerative Process
- Site Characteristics
- Successional Status
- Seasonal Development
- References

Species Value and Use
- Wood Products Value
- Importance to Livestock and Wildlife
- Palatability
- Food Value
- Cover Value
- Value for Rehabilitation of Disturbed Sites

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Other Uses and Values
Management Considerations
References

Plant Adaptations to Fire
General Adaptations to Fire
Lyon-Stickney Fire Survival Strategy
References

Fire Effects
Fire Effects on Plant
Discussion and Qualification of Fire Effect
Plant Response to Fire
Discussion and Qualification of Plant Response
References

Fire Case Studies
Case Name
References
Season/Severity Classification
Study Location
Preburn Vegetative Community
Target Species Phenological State
Site Description
Fire Description
Fire Effect on Target Species
Fire Management Implications

Using a computerized system simplifies information updating. It also permits wider access to and greater consistency in information transferred from researchers to managers. When implemented, the system will be accessible to anyone with computer-to-computer communication capabilities.

FEIS has the potential to "capture" good information that may not be published in the established literature. Good local studies and rules of thumb used by experienced managers in their use of fire can quickly be made accessible to a broad audience once the information is included in the system.

The system's flexibility, logical organization, and ability to handle large amounts of complex information are the result of applying artificial intelligence programming techniques. FEIS contains information on over 240 plant species, including whitebark pine, limber pine, and other species that occur in high-elevation environments. Current plans are to increase the number of coniferous forest plants and communities represented in the system so that information available on high-elevation Rocky Mountain species should expand rapidly in the near future.

During early development of the program, the prototype system was demonstrated at several dozen field locations in Arizona, Idaho, Nevada, Oregon, South Dakota, and Utah. The participants listed the following potential uses of FEIS:

- prescribed fire plans
- fire rehabilitation plans
- escaped fire analysis
- land use plans
- exotic species control plans
- environmental assessments and impact statements
- vegetation management plans (range, wildlife habitat, and silvicultural prescriptions)
- training programs
- research facilitation

The prototype system is now being tested by managers in the Forest Service, Bureau of Land Management, and the National Park Service. Full implementation is expected within the next 2 to 3 years.

WHITEBARK PINE AND CUMULATIVE EFFECTS MODELING FOR THE YELLOWSTONE GRIZZLY BEAR

Bev Dixon

The Endangered Species Act mandates that a biological assessment be performed for any land uses or management activities that may have an impact on any listed species. Part of the biological assessment involves an analysis of the cumulative effects of existing and proposed activities upon a species or its habitat. In order to facilitate this process in grizzly bear habitat, a computerized cumulative effects assessment model was developed by an interagency modeling team for the Greater Yellowstone Ecosystem in 1984.

The basis for this computer model is a series of digitized maps and overlays. The base maps represent the vegetative makeup of an area. Homogenous vegetation types are delineated on aerial photos and the resulting polygons are transferred to 7.5-minute orthophoto quads. Field crews examine a sample of approximately 25 percent of the delineated aerial photos, assigning habitat and cover type codes to forested components and generic five-digit vegetation codes to nonforested components. Data collected by these crews are used as the basis for extrapolating vegetation codes to unsampled areas. Feedsite, scat, and radio relocation data gathered by the Interagency Grizzly Bear Study Team were analyzed to calculate the

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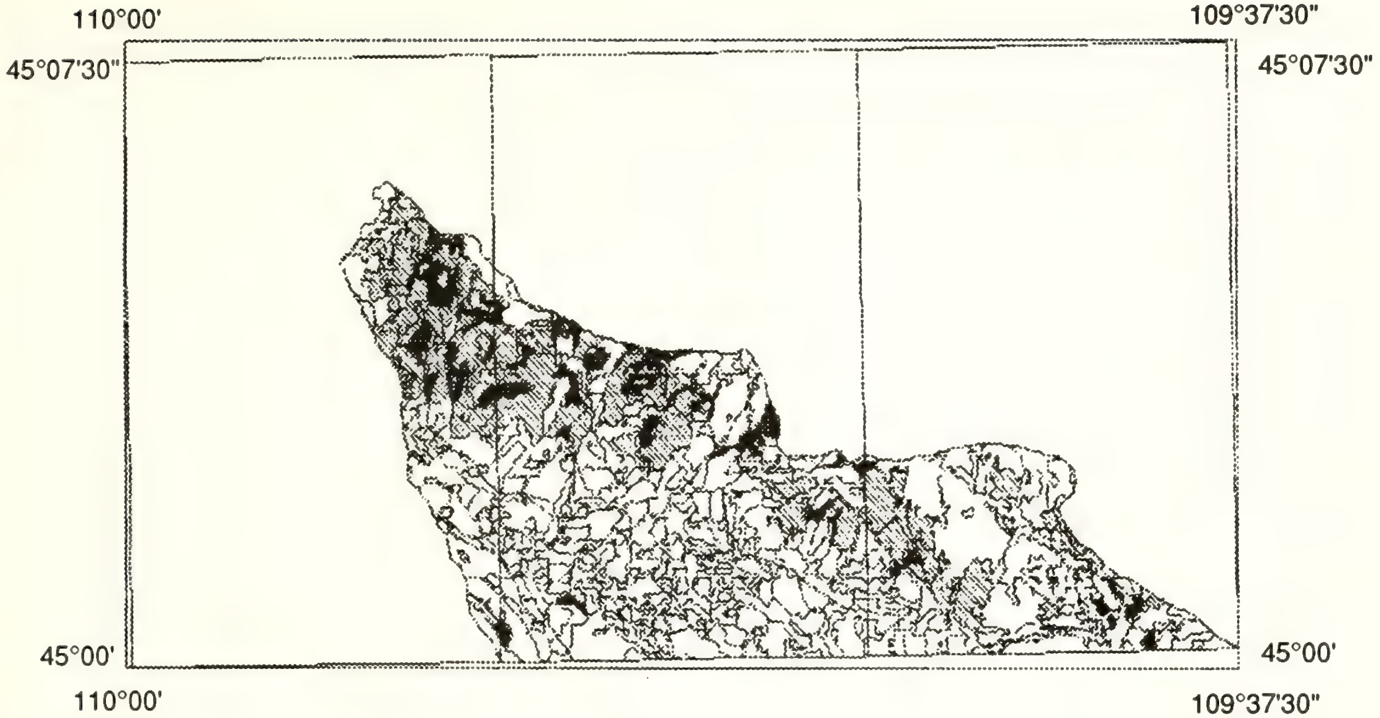

Figure 1—The geographic area represented here includes the northernmost portion (that portion that falls within the Gallatin National Forest boundary) of the Crandall/Sunlight Bear Management Unit of the Greater Yellowstone Ecosystem for grizzly bears. The border of the computer-generated vegetation maps represents the collective boundaries of three 7.5-minute USGS topographic quads: Alpine SW, Alpine SE, and Cooke City SW. The internal boundary represents the Bear Management Unit boundary. Polygons within the Bear Management Unit boundary represent homogenous units of vegetation. Polygons mapped as forested with substantial amounts of whitebark pine are shaded with a solid pattern. Polygons shaded with a cross-hatch pattern represent vegetation components mapped as mosaics of whitebark pine intermingled with other forest or nonforest types.

relative value to bears of the various vegetation components found throughout the Greater Yellowstone Ecosystem.

HABITAT VALUES

While vegetal structure is a critical element in grizzly bear habitat in terms of food and cover, animal food sources are also important as a source of protein for the bears. Therefore, areas of animal concentrations, such as ungulate winter ranges, are also mapped and this information is overlayed onto the vegetation base maps. The animal food sources generally increase the value of those vegetation polygons in which they occur.

Just as animal food sources increase the value of grizzly bear habitat, human activities typically tend to decrease the value of an area to the bears. Thus, sources of human activities, such as roads, trails, campgrounds, and picnic areas, are mapped and overlayed onto the habitat maps. Human activities vary in the degree to which they disturb bears based on the nature of the activity. For example, motorized activities are more disruptive to bears than nonmotorized activities. Occurrences of human activities in high-quality grizzly bear habitat tend not only to displace bears to lower quality areas, but also pose a degree of mortality risk to bears that remain in the area. All of these factors are considered in the cumulative effects assessment conducted as part of a biological assessment. This process is facilitated by the computerized cumulative effects model (CEM).

Whitebark pine (*Pinus albicaulis*) has been proven to provide an important food source to grizzly bears in the Greater Yellowstone Ecosystem. As such, whitebark pine is mapped to various successional stages in the vegetation component mapping process. In the manual "Forest Habitat Types of Montana," Pfister and others describe three specific habitat types containing whitebark pine. These types are: *Abies lasiocarpa-Pinus albicaulis / Vaccinium scoparium* (subalpine fir-whitebark pine/grouse whortleberry), *Pinus albicaulis-Abies lasiocarpa* (whitebark pine-subalpine fir), and *Pinus albicaulis* (whitebark pine) habitat types. Cover types used in the mapping process range in successional stages from recently burned whitebark pine stands (cover type 50—WBP) to stands of mature to overmature whitebark pine (cover type 54—WB). These habitat and cover types are combined to indicate occurrences of whitebark pine on the vegetation base maps.

USE OF MOSS

A Geographic Information System known as "MOSS" (Map Overlay and Statistical System) is currently used with the Greater Yellowstone Ecosystem cumulative effects model for visual display purposes. MOSS is used to display or "plot" the digitized vegetation base maps for viewing either on the terminal screen or printed out in hardcopy. MOSS commands also allow the user to select specific subjects or features on a map and highlight or shade these items to indicate their location on the map. Furthermore, queries can be made to obtain specific information pertaining to selected items within an analysis area, such as number of acres or linear miles, frequency of occurrence, percent of total acres, and other pertinent information.

For purposes of this synopsis, data collected from habitat component mapping for cumulative effects modeling on the Gallatin National Forest, along with MOSS, were used to locate and display potential sources of whitebark pine. Figure 1 provides a visual example of how this process can be used to delineate whitebark pine habitats in a specific management unit. This is another tool that helps increase the effectiveness of management practices on the ground.

CONTAINERIZED WHITEBARK PINE NURSERY PRODUCTION IN THE FOREST SERVICE NORTHERN REGION

Kent Eggleston and Joseph Meyer

The National Forests north of Yellowstone National Park are increasing their efforts in providing whitebark pine seedlings for wildlife habitat and reforestation enhancements. The Coeur d'Alene Nursery has been working with the Gallatin National Forest since 1985 by processing whitebark cones into clean seed and producing containerized seedlings for their outplanting program. Unlike other species produced at the nursery for the Forest Service Northern Region's reforestation programs, whitebark pine has presented several unique cultural and biological challenges.

SEED PROCESSING ACTIVITIES

The Coeur d'Alene Nursery has only recently begun to receive requests for whitebark pine seedlings and we have little experience in handling the cones, seeds, and seedlings (table 1). However, we have started work with whitebark pine and this synopsis is intended to show what we are doing.

Extracting seed from whitebark pine cones is more difficult than it is for other conifers and generally requires hand cleaning to assure seed removal. The seed tends to cling to the cone bracts, making machine (mechanical) cleaning difficult.

Stratification methods need to be refined for whitebark pine. Our records show that this species requires stratification procedures similar to western white pine. Germination is relatively poor. Our best results have been achieved by soaking one-half lb or smaller quantities in mesh bags for 48 hours in cold, running water. Following the soak, each mesh bag is placed inside a polyethylene bag to prevent drying, and the seed is put in the stratification room at 34 to 36 °F for 100+ days.

The Nursery is investigating several stratification methods and seed treatments to improve germination percentage and uniformity. The current treatment being tried is stratifying seed in containers. This method exposes a greater amount of the individual seedcoat surface area to the stratification environment. Another stratification procedure that could be investigated is the combination of warm temperatures prior to the normal cold environments. Both of these treatments have improved western white pine germination and may do likewise with whitebark pine.

SEEDLING PRODUCTION

Whitebark pine seedlings grow slowly compared to other conifers in the Northern Rocky Mountains. The Coeur d'Alene Nursery currently grows 4- to 6-inch seedlings in 3 to 4 months under normal greenhouse culture (table 2). Whitebark pine takes 6 to 8 months to reach those height standards. In order to reach height requirements, whitebark seed is currently sown two crop cycles prior to field planting. This allows the seedlings to be grown for one season inside a greenhouse, then allowed to set a terminal bud, then cold stored, and later grown for a second full season in the shelterhouse to reach adequate height before field planting.

The Nursery has just completed installing a new high-pressure sodium light photoperiod system in our Propagation House. This system enables photoperiod to be extended. This extended photoperiod increases the growing

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Table 1—Some specifics of whitebark pine seed received to date at the Coeur d'Alene Nursery

Year collected	Lot number	Date collected	Number bushel	Pounds	Yield (lb/bu)	Seeds/lb	Germination percent
1985	6410	8/17/85	5	13.80	2.76	4,400	2
1987[1]	6653	8/20/87	3	4.50	1.50	3,670	50
1987[2]	6654	8/20/87	1	.07			

[1]Seed for container-planting, fall 1990 in the Gallatin National Forest.
[2]Not enough seed to get testing information.

Table 2—Some specifics of current whitebark pine seedling production at the Coeur d'Alene Nursery

National Forest	District	Lot number	Container size	Number of seedlings requested	Elevation	Planting schedule	Habitat type
					Feet		
Gallatin	Hebgen Lake	6410	Supercel	12,000	8,600	Fall 90	ABLA PIAL/VASC
Gallatin	Gardiner	6410	Pinecell	2,000	8,600	Fall 88	ABLA PIAL/VASC

period from normal daylight period to 18 hours. In a preliminary test, whitebark pine sown under the longer photoperiod increased terminal bud length, but shoot height was little affected by the artificially generated longer daylengths. Apparently, we will still need the second growing season to get enough height development.

Another cultural method to be tested is to sow in April and grow until September of that same year before hardening off the seedlings for the next spring field planting. In the past, under intermittent light, this crop schedule produced premature budset. However, with the new extended photoperiod light system, continued stem elongation may be achieved.

VERTICAL DISTRIBUTION OF EPIPHYTIC LICHENS ON THREE TREE SPECIES IN YELLOWSTONE NATIONAL PARK

Sharon Eversman, Carol Johnson, and Dan Gustafson

Observations throughout Yellowstone National Park had indicated that lichen growth on trees is sparse, with less growth on trunks than on branches. A windstorm in July 1984 blew down thousands of trees in the *Pinus contorta-Vaccinium scoparium* vegetation type between Norris Junction and Canyon Village in Yellowstone National Park. We took advantage of the situation to investigate epiphytic growth on three tree species—lodgepole pine, whitebark pine, and subalpine fir. The location of the windthrow was near the Virginia Cascades road at an elevation of about 2,920 m (Wyoming, Park County, latitude 44°42' N, longitude 111°40'W).

Sharon Eversman is Associate Professor, Carol Johnson is Instructor, and Dan Gustafson is Graduate Student, Biology Department, Montana State University, Bozeman, MT 59717.

SAMPLING

It was very difficult to locate five trees each of whitebark pine and subalpine fir among the extensive numbers of lodgepole pine. When the whitebark pine and subalpine fir with accessible trunks were found, 1-m increments were marked from the base of the trunk to the tips.

Five trees of each species were sampled. Each circumference was divided into four "plots," roughly corresponding to north, south, east, and west exposures when the tree was standing. However, because some trees appeared to have twisted during their fall, the possible direction factor was eliminated during data analysis. Each circumference thus had four sampling plots except where the tree was flat against the ground or another tree at that sampling plot. Based on annual rings visible in nearby sawed trunks, the ages of the lodgepole and whitebark pines were estimated from 95 to 200 years, and the subalpine firs were 50 to 150 years old. Heights of the sampled lodgepole pine were 13.7 to 22.7 m (16 to 29 cm d.b.h.); whitebark pines were 8.1 to 14.0 m tall with d.b.h. of 10 to 20 cm; subalpine firs were 8.1 to 18.4 m with d.b.h. of 13 to 42 cm.

Pieces of outer bark from the three trees (six 350- to 400-mg samples) were soaked in distilled water for 30 minutes, blotted for 10 seconds, then air dried. Their weights were determined every hour for 4 hours to determine drying times of the different kinds of bark. The pH levels were determined by soaking slivers of outer bark (five 1-g samples per species) in 30 mL distilled water for 1 hour, then determining the pH of the water. Bark samples were taken 1.5 m above ground level.

FINDINGS

Most of the lichen species were tiny tufts of fruticose species and crustose forms; there were no bryophytes. Lichen growth was greatest at the base (mostly due to one species, *Parmeliopsis ambigua*) and above 2 m in height.

Seven lichen species grew on whitebark pine. They were, in order of frequency: *Lecanora piniperda, Bryoria lanestris, Parmeliopsis ambigua, Letharia vulpina, Letharia columbiana, Melanelia exasperatula,* and *Usnea fulvoreagens*. Lichens were contained in 59.8 percent of the 224 sampling plots on whitebark pine.

Lodgepole pine had only five lichen species on the trunks: *Parmeliopsis ambigua, Lecanora piniperda, Letharia vulpina, Letharia columbiana,* and *Bryoria lanestris*. Lichen growth was contained in 4 percent of the 360 sampled plots on lodgepole pine.

Subalpine fir had twelve lichen species on the trunks. All the species growing on whitebark and lodgepole pines also grew on subalpine fir. The five additional species on this tree were ones more usually associated with Douglas-fir or deciduous trees: *Xanthoria fallax, Physcia adscendens, Hypogymnia austerodes, Tuckermannopsis pinastri,* and *Parmelia sulcata*. Of 268 sampling plots on subalpine fir, 74.3 percent had lichen growth.

There were no differences in drying times of the three kinds of bark. The average pH of water medium after soaking bark was 4.94 for subalpine fir, 4.03 for whitebark pine, and 3.78 for lodgepole pine.

We concluded that subalpine fir had the most lichen growth because of the smooth nature of the bark, the highest pH, and most protected trunk bark. Whitebark pine had more lichen growth than lodgepole pine, perhaps because of the slightly less scaly bark and higher pH of whitebark pine compared with lodgepole pine.

INVENTORY, MONITORING, AND ANALYSIS OF WHITEBARK PINE ECOSYSTEMS USING THE ECODATA AND ECOPAC SYSTEM

Wendel J. Hann and Mark Jensen

ECODATA consists of a set of standardized sampling methods and data entry programs used in describing vegetation and site variables in the Northern Region of the Forest Service. Sampling methods range from rapid qualitative assessments of plant canopy cover to quantitative, replicated, statistical designs. The basic sampling methods of ECODATA describe site characteristics (such as soils, topography, and disturbance history), and general vegetation characteristics (such as species cover, age, size class, and height). Optional methods include techniques for assessing line intercept cover, nested rooted frequency, microplot cover, phenology, forage use, fuels, fire history, and riparian characteristics.

ECOPAC is an acronym for a series of menu-driven computer programs used in the analysis of ECODATA. Such programs allow the user to generate simple reports, conduct statistical analysis, display resource value ratings, and develop resource response predictions from ECODATA. Programs contained in ECOPAC include: Utility (used to scan for errors, produce reports, and analyze community types), Value (used to predict diversity, succession, forage value, fuels, fire behavior and effects, climate, and wildlife habitat suitability), Ecostat (used for

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cluster analysis, ordination, descriminant regression, and statistical analysis), and Ecolink (used to summarize plot data into polygon interpretations and link soil and water data bases with vegetation data bases).

In this presentation, various applications of ECODATA and ECOPAC were shown utilizing data collected from the whitebark pine ecosystem. Discussion of the need for standardized sampling and analysis of ecosystem variables also was presented.

ARTIFICIAL REFORESTATION OF WHITEBARK PINE

Richard L. Kracht and Ward W. McCaughey

With increased recognition of whitebark pine's importance in the management of wildlife habitat, watersheds, and recreation, it has become necessary to consider it in reforestation projects to help meet varied resource objectives. An administrative study was designed to evaluate standard reforestation techniques for effectiveness in regenerating whitebark pine. This study identifies climatic and site effects that appear to be important in survival and growth of whitebark pine seedlings.

METHODS

This study is located on the Gardiner Ranger District of the Gallatin National Forest 5.5 air miles east of Gardiner, MT. The planting site is on a 15-acre clearcut abutting a 50-acre clearcut called the Palmer Coop timber sale.

Whitebark pine cones were handpicked from trees adjacent to the planting site during late summer of 1985. Collections occurred during a short time period after the cones were mature and seed ripe, but just prior to harvesting of seed by Clark's nutcrackers and squirrels.

Seeds were extracted and cleaned at the Forest Service nursery in Coeur d'Alene, ID, according to standard nursery techniques. These techniques extracted approximately 50 percent of the seed, but the remainder of the seed required hand cleaning to remove it from the cones.

Seed germination tests indicated low germination of about 5 percent. However, other studies indicate that these tests may not have accurately indicated what the germinability was for this lot of whitebark pine seed. It is also possible that the cones were collected prematurely.

Seeds were cold stratified in the spring of 1986. One pound of seed per nylon mesh bag was soaked in running tap water for 48 hours and placed in cold storage between 34 to 36 °F for 100 days. The seed was then planted in the greenhouse in pine cell containers. Due to slow germination and slow initial growth, it was necessary to hold seedlings for a second growing season at the nursery to obtain enough seedlings of adequate size for planting.

The containerized seedlings were planted on the study site the fall of 1987 using standard reforestation practices: hand planting bars, selecting appropriate microsites, scarifying an 18-inch-square area to mineral soil, and providing natural shade. We staked and numbered 300 trees which were laid out in six parallel rows of 50 each. The seedlings were planted on a northeast aspect with planting sites distributed in a swale, up a side slope of 15 percent, across a bench (a ridge configuration), and down a gentle side slope of 9 percent. Survival counts were made during the spring and fall of 1988 and spring of 1989. We measured and recorded tree height to the nearest 0.5 cm and stem basal diameter to the nearest 0.01 cm during the fall of 1988, 1 year after outplanting.

RESULTS

Survival of whitebark pine seedlings has been good, with an 89 percent survival rate over the first 2 years. Overall survival was 97 percent for the initial overwinter period from the fall of 1987 to spring of 1988. Through the 1988 growing season, a record dry year, survival dropped to 91 percent. Seedling survival was 89 percent after the second overwinter period.

Seedling survival varied slightly in relation to topographic position. Survival was 100 percent on bench sites, 95 percent on 9 and 15 percent slopes, and only 80 percent in swales (fig. 1).

First-year growth of whitebark pine seedlings varied considerably by topographic position for height increment and slightly for basal diameter increment. First-year height increment averaged 1.8 cm for all seedlings—2.7 cm in swales, 1.9 on 9 percent slopes, 1.4 on benches, and 1.3 cm on 15 percent slopes (fig. 2). Basal diameter increment averaged 0.0497 cm in swales, 0.0475 and 0.0473 on 9 and 15 percent slopes, respectively, and 0.0447 cm on benches (fig. 3).

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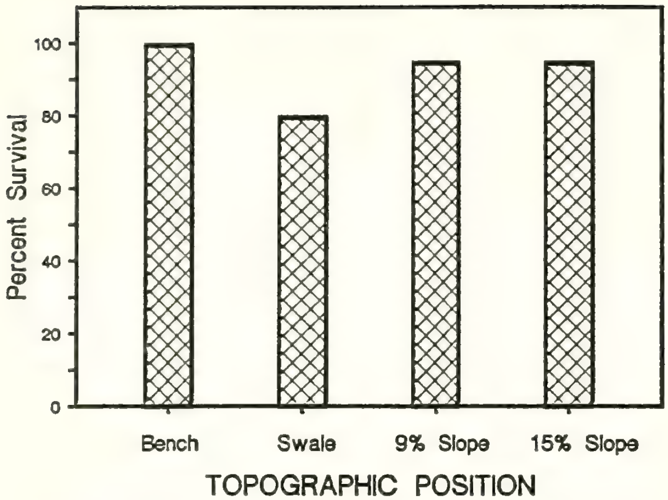

Figure 1—First-year survival of whitebark pine seedlings by topographic position.

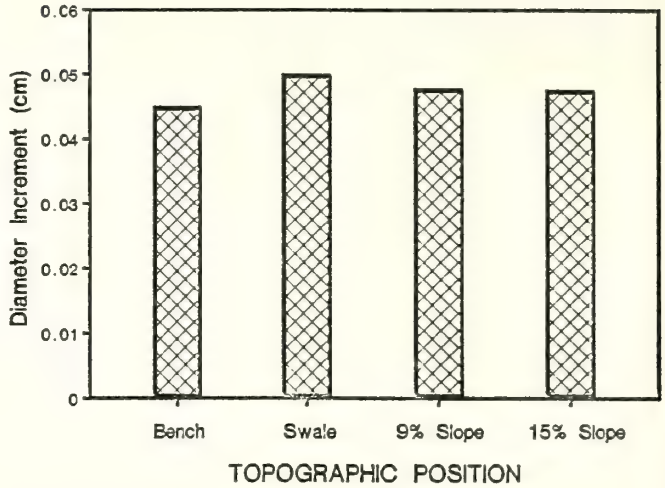

Figure 3—First-year increment of stem basal diameter of whitebark pine seedlings by topographic position.

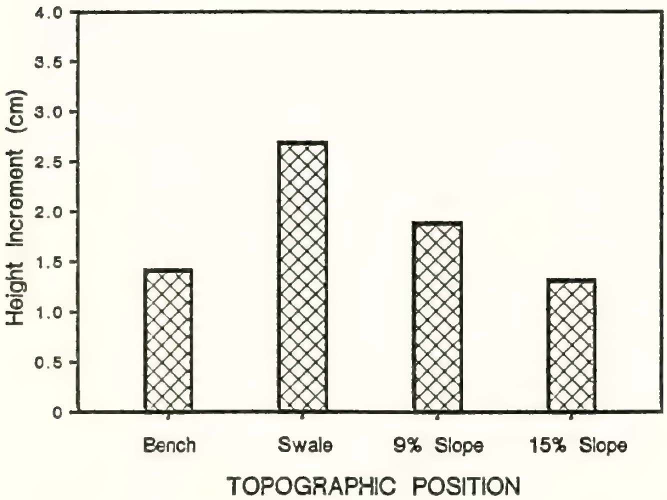

Figure 2—First-year height increment of whitebark pine seedlings by topographic position.

DISCUSSION

These preliminary results indicate that artificial reforestation of whitebark pine using standard operational techniques can succeed. These results are comparable with those of the National Forest System's reforestation program.

Whitebark seedlings may be influenced by topographic location both in survival and in height and diameter growth. Although preliminary, it appears that the moister and possibly cooler (frost pocket) conditions in the swale have resulted in slightly lower survival but have enhanced growth of surviving seedlings. Further monitoring of this administrative study should yield more definitive results.

This study has helped to pinpoint further work that will be needed to ensure a cost-effective operational planting program with whitebark pine. This is:

1. Development of seed collection zones.
2. Development of field procedures for determining when seed is mature.
3. Development of seed extraction and cleaning equipment.
4. Development of seed-stratification procedures.
5. Development of optimum growth regimes for nurseries.
6. Recognition of optimum growing sites for highest survival and growth.

To our knowledge, this is the first operational planting of whitebark pine seedlings. A second plantation has recently been established on the Rocky Mountain Ranger District near Choteau, MT. However, survival and growth measurements have not been taken yet. Hopefully these studies will lead to better management of these high-mountain forests.

MORPHOLOGICAL DIFFERENCES BETWEEN WIND-DISPERSED AND BIRD-DISPERSED PINES OF SUBGENUS *STROBUS*

Ronald M. Lanner

Two thirds of the world's Haploxylon (= subgenus *Strobus*) pines have nutlike seeds that cannot be dispersed by wind because: (a) seed wings are absent (these include *Pinus koraiensis, cembra, pumila, sibirica, albicaulis,* some *flexilis,* some *strobiformis, armandii, cembroides, edulis, monophylla, johannis, remota, juarezensis, culminicola, maximartinezii, pinceana, nelsonii, discolor*); (b) their seed wings are ineffective (some *flexilis,* some *strobiformis,* some *ayacahuite,* some *parviflora*); or (c) their seed wings stick to the cone-scale surface (some *parviflora, gerardiana, bungeana*).

Therefore, only a minority of the *Strobus* pines have the wind-dispersible seeds thought to be typical of the Pinaceae: (*aristata, balfouriana, longaeva, strobus, monticola, lambertiana,* most *ayacahuite, peuce, griffithii, dalatensis, morrisonicola, wangii, fenzeliana*).

The seeds of several of these non-wind-dispersible species are known to be dispersed and stored in the soil by birds of family Corvidae who use them as a food source. In North America, studies of pinyon pines (*edulis* and *monophylla*) have shown them to be dispersed and cached on a large scale by pinyon jays, and on a lesser scale by Steller's and scrub jays. These pines as well as *albicaulis, flexilis,* and *strobiformis* are dispersed and cached also by Clark's nutcracker. Several pines in Europe and Asia (*cembra, pumila, sibirica)* have been shown to have their seeds harvested and cached by the widespread Eurasian nutcracker. In all of these pine-Corvid systems, seeds stored in the soil in mast years exceed the birds' winter food requirements and become available for germination. In at least one species (*albicaulis*) there is no other regenerative method, and the tree depends on the bird for survival.

The "bird pines" differ from the conventional, or archetypical *Strobus* pines ("wind pines") in numerous morphological traits. The characteristics of bird pines facilitate seed harvest by Corvids, or survivability of seeds adapted to Corvid dispersal. I argue that these traits have arisen through natural selection exerted by the Corvids; and that it is this selection pressure that has led to the speciation of the bird pines from the older, more conservative wind pines.

TRAIT DIFFERENCES

For example, consider crown form. "Wind pines," such as *strobus, monticola, griffithii,* and *peuce,* are typically monopodial, seldom forked, and horizontally branched. The result is that they have relatively few cone-bearing branches, many of their cones are concealed by layers of foliage, and most of their cones are not readily visible to flying birds (poor display) or even birds perched on the crown. For these reasons, "wind pines" are not especially attractive to Corvids.

On the other hand, "bird pines," like *flexilis, albicaulis,* and the pinyons, are sympodial, frequently forked, and have numerous vertically oriented branches. This results in many cone-bearing branches, and cones that are well displayed to flying birds or to birds perched on the crown. In this way, "bird pines" attract Corvids.

These groups of pines also differ in their cone attachment. Among the "wind pines," branches are usually horizontal. Cones have long peduncles, are pendent, and are loosely attached to the branch. This causes both branches and cones to be unstable in a wind. Corvids must hang upside down to harvest seeds from open cones, a harvest process that is physically difficult and demanding of energy.

"Bird pines" on the other hand, have vertical or upswept cone-bearing branches. The cones are sessile and rigidly attached to the branch. Therefore, branches and cones provide stable perches for birds harvesting the seeds, and Corvids can remain upright when harvesting seed, making the harvesting process easy and less demanding of energy.

One consequence of bearing cones on upswept limbs is the need for heat diffusion within the cones. Cones exposed to the sun endanger their developing seeds, and must diffuse heat to prevent seed proteins from being denatured. In the "wind pines," the cones are shaded by the horizontal branches of the whorls above. Little heat is accumulated, so the cone scales can be thin. But the "bird pines" have cones that are exposed to the sun. Perhaps the thickened cone-scale apophyses that typify the pinyons, *albicaulis, gerardiana,* and some other bird pines have evolved as heat-diffusion masses.

RETENTION DIFFERENCES

Seed retention in cones is a characteristic of many of the "bird pines." Among the "wind pines," the cones open when they dry in the autumn; then the seeds fall out and fly on the wind. The "bird pines" show far more variability. In the subsection *Cembrae,* for example, cones remain closed or open only a little, and the seeds remain inside the cone. In subsection Cembroides (pinyon pines), the cones open, but the seeds are retained by spermoderm "flanges" on the upper cone-scale surface. In some other species (*parviflora, bungeana, gerardiana*) the seed wing sticks to the cone scale, temporarily immobilizing seed.

Among the *Cembrae* (*sibirica, cembra, pumila, albicaulis, koraiensis*) all species have cone scales lacking the coarse-fiber tracheids found in other pine cones. Therefore, they do not open by the differential shrinkage of

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drying tissues, as do other pine cones; and they are easily broken off by nutcrackers seeking the seeds inside. When *Cembrae* cone-scales are broken off, the seeds remain held in the core of the cone, thus facilitating the nutcracker's harvest.

Among the *Cembrae, cembra, koraiensis,* and *sibirica* seeds have a prominently marked hilum that is displayed when the scale is broken off. Does this serve as a "target" for the nutcrackers? The studies necessary to answer this and many other fascinating questions have not yet been done.

MONTANA'S NATIVE PLANT SOCIETY

Jan Nixon and Anne F. Bradley

New in the State within the last 2 years, the Montana Native Plant Society (MNPS) is an organization devoted to learning more about the plants native to this State and region. Our membership ranges from professionals working in a plant-related field or academic areas to individuals who are simply interested in learning more about the flora of their area on a nontechnical level.

The purpose of the Montana Native Plant Society is: "The preservation, conservation, and study of the native plants and plant communities of Montana and the education of the public to the values of the native flora and its habitat." The society provides a forum for information exchange between scientists, educators, horticulturists, and interested lay people throughout the State of Montana.

MNPS puts on field trips throughout the year and local chapters meet monthly, offering programs on a wide range of plant-related topics. Other projects we are involved in include:

- a knapweed-suppression project at the Kirk Hill Nature Trail south of Bozeman, in cooperation with Museum of the Rockies;
- development of a data base detailing plant communities and species identified on field trips and outings;
- seed collecting in the Logan Pass area of Glacier National Park for revegetation efforts of some of the heavily impacted areas around the Visitor Center there;
- active involvement with the Montana Natural Heritage Program in searching for previously unknown populations of plant species of special concern to that program.

Anyone who would like to learn more about the native vegetation of Montana for scientific or commercial purposes, or for the sake of pure enjoyment, is encouraged to join. MNPS welcomes your interest and involvement with us as we increase our knowledge of the State's flora, its habitats, and importance. For more information contact either of the authors or Montana Native Plant Society, c/o Department of Biological Sciences, University of Montana, Missoula, MT 59812.

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WIND AND SNOW DAMAGE EFFECTS AFTER THINNING IMMATURE SUBALPINE FORESTS

Jack A. Schmidt

Whitebark pine and lodgepole pine are common associates in many subalpine forests of the Mountain West. This combination occurs at the lower elevational limits of whitebark pine and upper limits of lodgepole pine. Where they merge, densely stocked stands are common and whitebark pine assumes a tall, slender growth form similar to lodgepole pine.

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Overstocking often limits the resource values in this zone, and thinning is frequently used to open up the stand for increased light and moisture for reserve trees. This management action can alter wind and snow patterns, subjecting the reserve trees to stresses seldom encountered in densely stocked stands. This study, although aimed primarily at evaluating lodgepole pine, provides insights on the effects of wind and snow in thinned stands where whitebark pine may be a component in these high-elevation forests.

WHITEBARK PINE—A SUBALPINE SPECIES NEEDING SILVICULTURAL ATTENTION

Wyman C. Schmidt and Ward W. McCaughey

Whitebark pine is a conifer that occupies high-elevation areas of the Mountain West, providing some of the most picturesque "krummholz" forest scenes in America. Snow, ice, and wind sculpture trees in these forests—the forests reciprocate by protecting the soils and watersheds that support them. They also provide food and cover for many species of wildlife, particularly America's large carnivore—the grizzly bear.

Whitebark pine occurs in both mixed and nearly pure stands but will often be succeeded by the more shade-tolerant subalpine fir if fire does not intervene. This gradual change in species composition can have positive or negative effects depending upon the objectives of forest managers. Managers need more information about seed production and dispersal, germination requirements, seedling survival and growth, succession, insect and disease relationships, and interactions with other physical and biological factors. Many of these items are addressed in this "Whitebark Pine Symposium." Some of the things we do know about whitebark pine are:

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SEED DISPERSAL

Clark's nutcrackers are considered the main dispersal agent of whitebark pine and likely responsible, inadvertently, for most of the natural regeneration of whitebark pine. Nutcrackers extract whitebark pine seeds from cones in late summer, store up to 100 seeds in their sublingual pouch, and fly considerable distances to store them for later consumption. From one to several seeds are deposited in each of a number of caches in loose soil or duff at a depth of 2 to 4 cm. About half of these seeds are never recovered by the nutcracker and can germinate, often ending up as a clump of germinants.

SEEDLINGS

Whitebark seeds need at least 30 to 60 days of cold-moist conditions before they will germinate. Whitebark seedling growth is slow compared to its other conifer counterparts and this slow growth, particularly at the higher elevations, persists throughout its life.

SQUIRRELS

Red squirrels cut substantial portions of the whitebark cone crop during August and September and cache them in middens for winter food supplies. Although usually much smaller, middens may contain up to 3,000 whitebark pine cones. Middens are a natural attractant and

the whitebark pine seeds an important food source for both grizzly and black bear.

Pure stands of whitebark pine do not readily support red squirrel populations because cone crop failures of whitebark pine in some years leave them without a ready food supply. As a result, squirrel populations fare much better in mixed species stands because cone crop failures of the various species seldom totally coincide, leaving at least some food supply for the resident squirrels.

GRIZZLY BEAR

Grizzly bears frequent high-elevation forests in the Northern Rocky Mountains in search of food and cover. Whitebark pine forests, particularly in the Yellowstone ecosystem, provide both of these important components for this endangered species. Bears feed heavily in both spring and fall on whitebark pine seeds from cones cached by red squirrels. Studies by the Interagency Grizzly Bear Team show that whitebark pine seeds provide over half of the average dietary fat consumed by a grizzly bear over its lifetime in the Yellowstone ecosystem. Survival of grizzly cubs is usually higher in years following good cone crops of whitebark pine.

SILVICULTURE

National Park or Wilderness designation precludes the use of most silvicultural practices, but over much of the range of whitebark pine silviculturists are ultimately responsible for designing and implementing those practices needed to meet management objectives. To do this effectively silviculturists must have adequate information on cone and seed production and how this process can be regulated and predicted, must know the seedbed and other environmental requirements such as shade, moisture, and temperature for seed germination and seedling survival of the various combinations of species in these high-elevation forests, must know how to use prescribed fire effectively, must know how to successfully plant whitebark pine and its associates, and must know how seedlings develop and how immature stands can be cultured to help meet management objectives. All of the above must take into consideration insects such as the mountain pine beetle, cone and seed insects, and diseases such as blister rust.

The days of "healthy neglect" of these forests are likely coming to an end because the results of near-complete fire exclusion are becoming increasingly apparent and the impacts of insects and disease are increasing. All of this becomes more complicated when the possibility of long-term global warming is taken into account. Global warming may reduce the width of that high-elevation zone where the rigorous climate enables whitebark pine, and its high-elevation associated species, to compete successfully with the more mesic species immediately below. Whitebark pine could essentially be "pushed off the top of the mountain" by those tree species better adapted to warmer conditions. Thus, there are many challenges ahead in these forests that have seen little attention by silviculturists.

SUMMARY

Whitebark pine forests merit the increased attention of managers and researchers throughout the Mountain West. The importance of these forests for wildlife, watershed, esthetic, timber, and associated resource values is being increasingly recognized. Information already available on the basic ecology of these forests helps illustrate the complex interactions of mammals, birds, and other biological and physical phenomena—it also points out the need for much more information. The emerging importance of these forests will hopefully prompt accelerated research that helps fill knowledge gaps about these subalpine forest ecosystems and ultimately show how they can best be managed. These subalpine forests truly need increased silvicultural attention.

AUTECOLOGY OF WHITEBARK PINE: CLUSTER AND MICROSITE CHARACTERISTICS

Sharren K. Sund, Diana Tomback, and Lyn Hoffmann

In 1961, over 11,000 ha of subalpine forest were destroyed in the Sleeping Child Burn (Sapphire Range, Bitterroot National Forest, western Montana). Our 1987 study of whitebark pine (*Pinus albicaulis*) regeneration in the burn produced data on tree clusters and microsite characteristics. Three parallel series of plots (total number of plots = 63) were sampled along a 3.5-km, east-west ridge from the whitebark pine seed source in the adjacent forest to the northern center of the burn. Each plot series represented a different aspect: north, south, or ridge (west).

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Analyses of tree cluster sizes (number of individual trees/site) showed whitebark pine clusters on the south plot series to be significantly smaller than clusters on north or ridge plot series. Cluster sizes ranged from one to eight trees; as cluster size increased, percentage of clusters in each size category decreased. In virtually all clusters no tree stems were fused at the base, indicating that each member of a cluster appeared to be a distinct individual. Ages of individual trees within a cluster were the same or similar, usually differing by only 1 or 2 years, but in no case more than 4 years. Age ranges were nearly identical for the three plot series, but trees on the north series had a slightly lower mean.

Frequencies of plant species growing near whitebark pine clusters indicated similarities between aspects, with ridge microsites intermediate between north and south. Three plant species (*Vaccinium scoparium, Carex rossii,* and *Polytrichum*) accounted for the majority of microsite occurrences. Distinct differences were noted between whitebark pine microsite vegetation and characteristic plot series vegetation. "Objects" ranging from small wood pieces to rocks and standing snags were found on 80 percent of whitebark pine microsites.

EFFECTS OF TRAMPLING ON THE UNDERSTORIES OF WHITEBARK PINE FORESTS

T. Weaver and D. Dale

Pinus albicaulis understories are often a low carpet of *Vaccinium scoparium* or graminoids. In 1973 the impact of hikers, motorcycles, and horse trampling on such vegetation was compared experimentally by periodically measuring the depth, width, vegetational cover, and soil bulk density of trails traversed by each trampler (Weaver and Dale 1978). On level ground, damage increased from hiker to cycle to horse, apparently in proportion to the pressures applied. Going up a 25 percent slope, damage increased from hiker to horse to cycle, probably because the cycle tended to "spin out." Going down a 25 percent slope, damage increased from cycle to hiker to horse, probably because hikers and horses tend to "dig their heels in" rather than rolling. Adaptations leading to trampling resistance include flexibility, prostrate life form, and a life cycle completed out of the trampling season (Dale and Weaver 1974; Weaver and others, this proceedings).

Recovery from trampling damage is more rapid in meadow than forest vegetation. The experimentally trampled areas in meadow vegetation were quickly revegetated and almost impossible to distinguish from untrampled areas after 5 years (Weaver and others 1979). Despite lack of subsequent trampling, trampled areas in the *Pinus albicaulis-Vaccinium scoparium* forest were easily distinguished after 5 years (Weaver and others 1979). After 15 years, forest areas traversed 1,000 times on both level and sloping sites still have markedly higher soil bulk densities than less trampled areas and a lack of understory plant growth. One thousand traverse trails are clearly visible, 500 traverse trails are generally visible, and 100 traverse trails are very faint. Trampling effects may persist under forest conditions both because of greater soil stability (for example, less annelid, gopher, and frost churning) and because of overstory competition for resources (light, water, and nutrients) needed for understory plant recovery.

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REFERENCE GUIDE TO WHITEBARK PINE

Ward W. McCaughey
T. Weaver

The purpose of this guide is to provide an easy access to literature about whitebark pine (*Pinus albicaulis*) for those managers and researchers who are concerned with this species. Because of the uniqueness of the species and the lack of concentrated research programs in the past, documents about whitebark pine are found in a wide variety of places, including some rather obscure sources. We assembled this guide to help those needing access to whitebark pine information.

This document references all the literature we could find specific to whitebark pine. Biological Abstracts from 1927 to 1988 was our primary source of references; therefore, bioabstract index numbers are provided to give the user easy access to the author's own annotation. Other papers listed in Forestry Abstracts and Agricola were added. The papers included in this symposium proceedings are not listed here.

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Includes 52 papers and 14 poster synopses that present current knowledge about ecosystems where whitebark pine and associated flora and fauna predominate. This was the first symposium to explore the ecology and management of these ecosystems, which are becoming increasingly important.

KEYWORDS: *Pinus albicaulis*, stone pines, Clark's nutcracker, climate, autecology, community types, succession, fire influences, seed germination, establishment, stems, chemistry, insects, diseases, berries, history, grizzly bears, deer, red squirrels, seed dispersal, hydrology, recreation, genetics, silviculture

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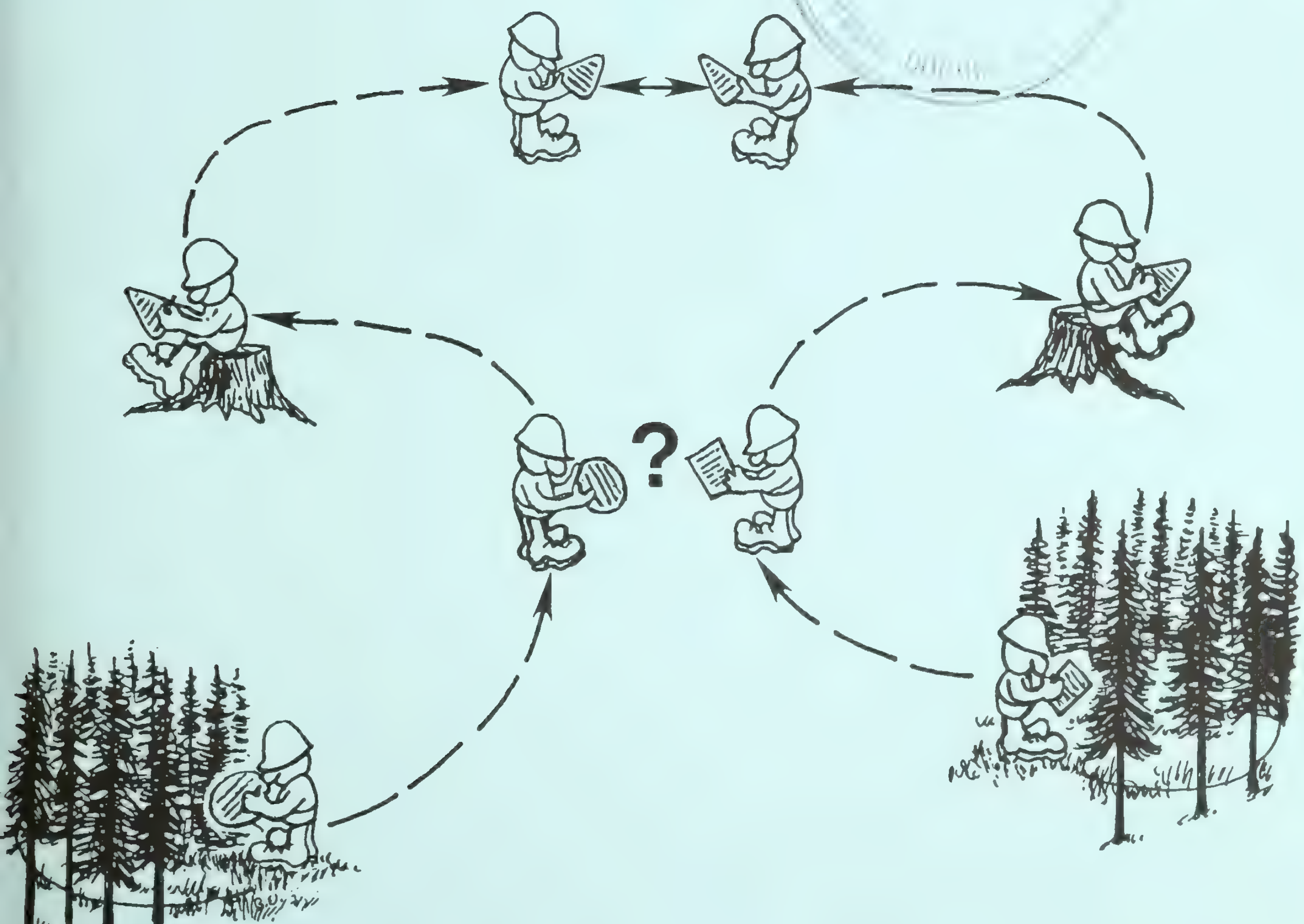
A Standardized Data Structure for Describing and Exchanging Data from Remeasured Growth and Yield Plots

Michael D. Sweet
John C. Byrne



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In the early 1970's James Arney and others at Weyerhaeuser Company and Jill Hoopes and Robert Curtis of the Pacific Northwest Forest and Range Experiment Station (PNW) designed a series of programs for processing permanent plot data. In 1976, Don Reimer, employed with MacMillan-Bloedel, chaired the Western Forestry and Conservation Association's Committee on Standards of Measure and Data Sharing (COSMADS). The COSMADS format, maintained by the British Columbia Ministry of Forests, provided a basis for PNW's Plot Data Management System (PDMS). Gary Clendenen's and Robert Curtis' documentation of PNW's PDMS data formats, James Arney's knowledge of the original Weyerhaeuser-PNW project, and Frank Hegyi's documentation of the COSMADS data formats provided a sound foundation for the development of this data structure. We are strongly indebted to those who preceded us. Major support for this study was provided by the Inland Northwest Growth and Yield Cooperative (INGY) through a cooperative agreement with the University of Montana School of Forestry's Mission-Oriented Research Program and the Intermountain Research Station, Moscow, ID.

RESEARCH SUMMARY

Collectively, public agencies and private industry are currently maintaining a large number of permanent growth and yield research plots. To facilitate the sharing of plot data for the development, testing, and improvement of tree or stand growth models, standard data definitions and formats are required to maintain data integrity. Since the 1970's, standards for documenting permanent plot data have generally been available, but have lacked the capability to fully describe sampling designs, measurement methodologies, individual tree characteristics, and treatment histories. We propose a data structure that addresses these deficiencies and that provides a standardized format for the exchange of permanent plot data.

CONTENTS

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INTRODUCTION

In 1986, the Inland Northwest Growth and Yield Cooperative funded a project to develop a database of forested permanent growth and yield plots for the purpose of testing and improving growth and yield models. This required merging data from a variety of cooperators, each with its own measurement standards and data definitions. To expedite development of the database, maintain data integrity, and provide a foundation for communicating data needs, common definitions and formats had to be agreed upon. The objectives in establishing standardized data formats and definitions were:

1. To define a data structure, independent of hardware and software, that easily allows cooperators to exchange and analyze permanent plot information.
2. To develop data formats and definitions that allow for varying sampling designs, English or metric measurement units, and varying degrees of measurement precision.
3. To define a data structure that does not require, but allows for, tree-level information at each measurement period.
4. To provide a data structure that can be readily expanded to accommodate existing or new information as needs change.

The primary geographic area of interest includes Montana, northern Idaho, eastern Washington, Alberta, and interior British Columbia. This data structure was designed for research and monitoring plots (USDA Forest Service 1990) and may not be suitable for remeasured inventory plots. The data definitions and formats presented here were developed through a cooperative effort among the University of Montana Mission-Oriented Research Program; the Intermountain Research Station's Forestry Sciences Laboratory at Moscow, ID; and members of the Inland Northwest Growth and Yield Cooperative.

EXISTING DATA STRUCTURES

In the early 1970's the Weyerhaeuser Company and the Pacific Northwest Forest and Range Experiment Station initiated an effort to develop a common permanent-plot database to support the construction of Douglas-fir yield tables. Included in this effort was the development of a series of computer programs for data management and analysis. In 1977, the Western Forestry and Conservation Association's Committee on Standards of Measure and Data Sharing (COSMADS) expanded on the initial database effort by cataloging permanent plots in the Pacific Northwest and setting standards for permanent sample plots (Arney and Curtis 1977). COSMADS first recognized the role of a standardized format as an intermediary or translator between a donor's format and a receiver's format. COSMADS also noted that standardized formats serve only as guidelines, not absolutes. Standardized data formats must be adaptable to the needs of an organization, but in return each organization must see the "greater good" of developing common data sets.

The COSMADS data formats and database are currently maintained by the British Columbia Ministry of Forests. In 1981, Curtis and Clendenen (1981) began to integrate the computer programs developed in 1970 for the Douglas-fir yield tables into a Plot Data Management System (PDMS). Each of these efforts provided a sound foundation for the Inland Northwest Growth and Yield Cooperative to build on, but none of the existing data structures fully met the objectives of this project. Previous data structures lacked the capability to fully describe different sampling designs, measurement methodology, individual tree characteristics, and treatment history. Appendix G presents a summary comparison of the data structure presented here and the COSMADS and PDMS formats.

OVERVIEW

Record and Field Descriptions

The data structure described here logically groups related information into "records." Each record is limited to 80 columns in length for ease in viewing on a standard video display or printer. This feature is particularly advantageous when exchanging information. COSMADS recognized that forest growth data were a "highly dynamic, distributed, large volume data set," which prohibited the development of a centralized data bank. In the absence of centralized data management, ease in exchanging information had to be given top consideration. A maximum record length restriction of 80 columns was limiting for only a few records. Overall, a limit on record size proved to be advantageous because it forced the grouping of data fields into manageable subsets.

Each record begins with a series of fields that identify to which stand or plot the information belongs. This "identifier" is followed by a three-digit code, called a "record type," which references what kind of information is contained in the remainder of the record.

The records are grouped into three major categories—core, supplemental, and individual tree. The "core" records document sampling design, administrative descriptors, geographic location, plot descriptors, plot summary information, measurement dates, treatment, and site descriptors. COSMADS recognized the proprietary nature of permanent growth data and defined the need for a reference file or catalog approach that did not include tree-level data. In essence, the core records defined in this paper are equivalent to the COSMADS reference file approach. Full completion of the core records is considered essential if a user is to assess the utility of a particular plot without accessing the tree data. If a specific core record is missing, the user might assume no information exists for that record and reject it for analysis, when in fact, the information was available but not supplied. Supplemental records augment information in the core records. They are defined for soils, climate, height/d.b.h. regression coefficients, and administrative units. The individual tree records contain detailed information on each tree measured.

All information within a record occurs in contiguous, fixed-field (fixed-column) format. Fields within a record are defined sequentially from left to right and begin with column 1. Each field within a record is described by a field label, data format, and description. The field label is a descriptive name for the data field. The data format is defined by a single character indicating the data type, followed by a digit indicating the maximum width of the data field. The data format for numeric fields are preceded by an "N" (N5), and character fields are preceded by a "C" (C4). If the numeric field is intended for real numbers rather than integers, the field width is followed by a decimal point and a digit indicating the maximum number of acceptable decimal places following the decimal point. For example, a numeric field for real numbers with a data format of N5.2 allows for two digits to the left of the decimal, the decimal point, and two digits to the right of the decimal for a total field width of five.

Within a field, all numeric data (integers and real numbers) are right-justified in the field, and all character data are left-justified. For real numbers, the decimal point occupies one column in the field and is always included to prevent errors

when data are translated into other formats or accessed by other software. Dates always appear in the ANSI (1977) standard format of year, month, day to avoid confusion between the different date formats used in the U.S. and Canada. Except where logical and clearly stated, zeros and blanks are considered missing information.

Stand and Plot Identification

Each plot is referenced by a unique identifier. This identifier, termed a "key," occurs at the beginning of each record and is formed by concatenating five numeric fields together. The fields that comprise the key and their formats are described below. The key is numeric for three reasons—it is compact, easily adaptable to iterative data processing such as sorting, and can be used to "mask" plot identification when exchanging proprietary data.

Each record is internally referenced and uniquely identified by including this key in the first 14 columns. For example, if all records were grouped into one file or a relational database structure was used, this key would allow the user to quickly identify all records belonging to a single plot, stand, or installation. For users who would like to cross-reference this key to another type of identifier, or carry a more readable identifier within the database, the administrative units record (record type 230) is available.

Field name	Format	Description
Source	N2	The source is a user-defined numeric code that uniquely identifies all information associated with a particular contributing organization. All records for a single organization have the same source code. Any organization receiving information can reassign this code to maintain the uniqueness of the key within their own database.
Installation	N4	An installation number identifies a logical grouping of stands, typically limited to a specific geographic locality. Each installation number is unique within a source.
Stand	N2	A stand is defined as an area of ground with relatively uniform conditions and a unique treatment combination. Each stand number must be unique within an installation.
Plot	N4	The collection of trees included within a single sampling unit. For fixed area plots, the sampling unit includes all trees within a circumscribed area. For variable radius plots, the sampling unit is the specific set of trees about a point. Each plot number is unique within a stand.
Subplot	N2	Defines a sub-sampling scheme for a plot. Subplots lie within a plot and may or may not utilize the same plot center. All subplots have the same plot number.

The fields listed above are hierarchical. The purpose of this hierarchy is to encode within the plot identifier the relationship between the area being sampled (installation, stand) and the samples collected (plot, subplot). Subplots occur within a plot, plots occur within a stand, and stands occur within an installation. The values for these numeric fields are user-defined and assigned by the contributing organization's database manager. For example, a University of Montana plot coded as source 1, installation 478, stand 2, plot 1 would result in the key 01047802000100 (source = 01, installation = 0478, stand = 02, plot = 0001, subplot = 00).

Depending on the record type, information is recorded at either the stand level or plot level. Information that does not change from plot to plot within a stand, for example treatment history, is recorded only once at the stand level. By not duplicating stand level information for each plot and subplot within the stand, the potential for

error is greatly reduced and the database is easier to maintain. Stand level information is differentiated from plot level information by setting the plot and subplot fields to zero. When retrieving information for a specific plot or subplot, specifying the corresponding installation and stand code will retrieve all of the associated stand level information. Each record type, as it is discussed, will be identified as either stand level or plot level.

Two examples follow to illustrate how the plot identification fields are coded.

Example One—Installation 478 contains two stands (fig. 1). Each stand is approximately 3 acres in size. The treatment applied to stand 1 resulted in a 10-foot spacing, and the treatment applied to stand 2 resulted in a 20-foot spacing. Three sample plots were randomly placed within each stand. The plots are one-fifth acre in size, with a 1/300-acre subplot, and coded as:

Source	Installation	Stand	Plot	Subplot		
1	478	1	1	0	–	Stand 1, 1/5-acre plot
1	478	1	1	1	–	Stand 1, 1/300-acre subplot
1	478	1	2	0	–	Stand 1, 1/5-acre plot
1	478	1	2	1	–	Stand 1, 1/300-acre subplot
1	478	1	3	0	–	Stand 1, 1/5-acre plot
1	478	1	3	1	–	Stand 1, 1/300-acre subplot
1	478	2	1	0	–	Stand 2, 1/5-acre plot
1	478	2	1	1	–	Stand 2, 1/300-acre subplot
1	478	2	2	0	–	Stand 2, 1/5-acre plot
1	478	2	2	1	–	Stand 2, 1/300-acre subplot
1	478	2	3	0	–	Stand 2, 1/5-acre plot
1	478	2	3	1	–	Stand 2, 1/300-acre subplot

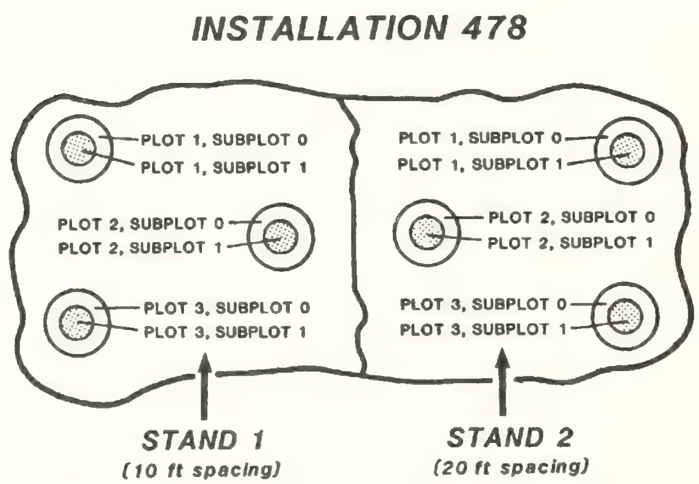

Figure 1—Stand and plot layout for sample installation number 478.

Example Two—Installation 520 contains eight stands (fig. 2). Each stand is slightly larger than one-fifth acre in size. Each stand contains one plot, one-fifth acre in size, and a 66-foot plot buffer. Each stand received one of four possible treatments (no treatment, 10-, 15-, or 20-foot spacing). These plots would be coded as:

Source	Installation	Stand	Plot	Subplot		
1	520	1	1	0	–	Stand 1, 1/5-acre plot
1	520	2	1	0	–	Stand 2, 1/5-acre plot
1	520	3	1	0	–	Stand 3, 1/5-acre plot
1	520	4	1	0	–	Stand 4, 1/5-acre plot
1	520	5	1	0	–	Stand 5, 1/5-acre plot
1	520	6	1	0	–	Stand 6, 1/5-acre plot
1	520	7	1	0	–	Stand 7, 1/5-acre plot
1	520	8	1	0	–	Stand 8, 1/5-acre plot

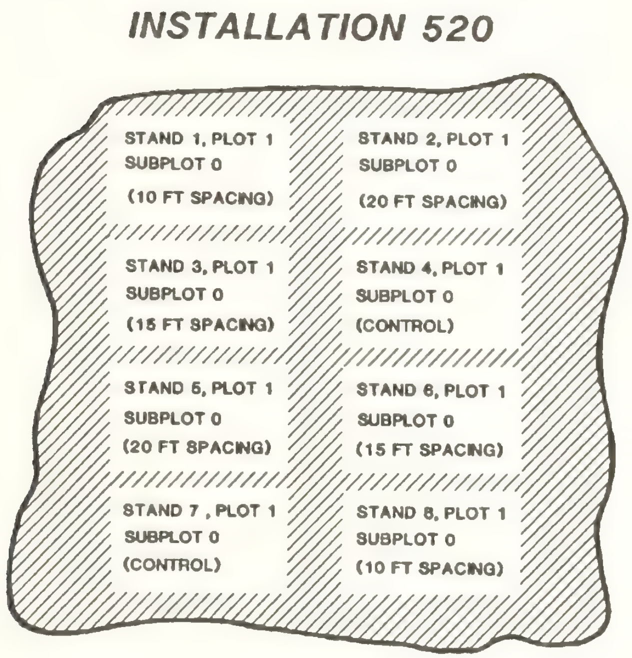

Figure 2—Stand and plot layout for sample installation number 520.

Basic Record Types

Each record type identifies a logical grouping of data fields. The first digit of the three-digit record type number signifies a generalized category of information. The following scheme was used to assign record type numbers:

100's = sampling design
200's = administrative and geographic location
300's = plot descriptors
400's = measurement history
500's = treatment history
600's = site and climate
700's = other
800's = individual tree
900's = comments

When developing new record types, it is advantageous to assign record type identifiers according to the scheme outlined above.

CORE INFORMATION

The core records document sampling design, administrative descriptors, geographic location, plot descriptors, plot summary descriptors, measurement dates, treatment, and site descriptors. This basic information is necessary to fully describe the characteristics of a growth and yield plot independent of tree-level data. The core records are not only useful for analytical reasons, but allow for global searches of a permanent-plot database without having to access individual tree information. Table 1 provides an overview of the core records. Each record is discussed in detail on the following pages.

Table 1—Summary of the core records

Record	Record label	Description
110	Sampling design	Subpopulation characteristics, sampling rule, expansion factor, number of samples, unit of measure. One or more records for each stand.
210	Administrative descriptors	Project name, installation name, administrative organization, owner. One record for each stand.
220	Location descriptors	State, latitude, longitude, UTM coordinates, legal description. One record for each stand.
310	Plot descriptors	Status, stand origin, timber type, site index, age, buffers, sampling design. One record for each plot.
320	Plot summary	Trees per unit area, mean diameter, basal area per unit area, and top height by species and measurement number. One record for each species recorded, each time the plot was measured. An additional record is completed to represent the plot total.
410	Measurement dates	Date for each measurement. One record for each year (a growing season) the plot was measured.
510	Treatment	Date and type of treatment. One record for each treatment the stand received.
610	Site descriptors	Elevation, aspect, slope, topographic position, and bioclimatic zone. One record for each plot.

110. Sampling Design

The sampling design record documents (1) the criteria used to select the sample, and (2) the multiplier to be used when expanding tree data to a per-unit-area basis (expansion factor) for each stand within an installation. The fields for describing sampling design were developed by Byrne and Stage (1988) and were modified to be consistent in structure with other record types. Byrne and Stage thoroughly discuss and provide many examples of implementing the sampling design record.

There are two key reasons why stand, rather than plot or subplot, was chosen as the lowest common denominator when describing sampling design. First, by definition a stand is an area of ground with relatively uniform conditions and a unique treatment combination. It is this combination of uniformity and uniqueness that is being sampled through the use of plots. The effectiveness of sampling is diminished in stands with widely varying plot designs. Therefore, the usual case is to have one sampling design applied to all plots within the stand. Secondly, the integrity of the sampling design information is maintained by not duplicating this information for each plot within a stand.

The sampling design record has two logical groups of fields in addition to the plot identification fields. The first group of fields describes the subpopulation being sampled. This description consists of an identifier (subpopulation number) and several attributes that characterize the subpopulation. The second group of fields describes the sampling rule being applied to the subpopulation. These consist of an identifier (sampling rule number), the variable defining the probability used, the expansion factor, the number of samples, and the unit of measure used.

The subpopulation and sampling rule identifiers, in combination, uniquely identify the sampling design used. One record is completed for each unique sampling design within a stand. In most cases only one record is needed, but it is possible for a stand to have more than one sampling design. Multiple sampling design records may be the result of a sampling approach that varies slightly for a portion of the plots within a stand, or because the design has changed over time as a response to changing informational needs.

The sampling design information is essential for properly calculating summary attributes such as trees per acre and basal area. Because sampling design is recorded at the stand level, the design associated with a particular plot or subplot within the stand needs to be referenced. To do this, the appropriate subpopulation number and sampling rule number are recorded on the plot descriptors record (record type 310).

Field name	Format	Description
Source	N2	
Installation	N4	
Stand	N2	
Plot	N4	Always zero.
Subplot	N2	Always zero.
Record type	N3	110.
Subpopulation number	N1	A sequential number. Within a stand, this number uniquely codes the subpopulation being described.
First subpopulation characteristic	C1	The first characteristic used to define the subpopulation being sampled. D = according to some d.b.h. limit. H = according to some tree height limit. T = according to a tree class code. (Alive, dead, etc.). C = according to a tree condition code. (Insects, disease, etc.). S = according to a species code.
Minimum limit for first subpopulation characteristic	C5	Minimum value or the first nominal code for the first subpopulation characteristic. For continuous variables (D and H above), record the minimum value (format is N5.1). For nominal variables (T, C, and S above), record the code or value used.
Maximum limit for first subpopulation	C5	Maximum value or a second nominal code for the first subpopulation characteristic. For continuous variables (D and H above), record the maximum value (format is N5.1). For nominal variables (T, C, and S above), record the code or value used.
Second subpopulation characteristic	C1	The second characteristic used to define the subpopulation being sampled. As above, record D, H, T, C, or S.
Minimum limit for second subpopulation characteristic	C5	Minimum value or the first nominal code for the second subpopulation characteristic. For continuous variables (D and H above), record the minimum value (format is N5.1). For nominal variables (T, C, and S above), record the code or value used.
Maximum limit for second subpopulation characteristic	C5	Maximum value or a second nominal code for the second subpopulation characteristic. For continuous variables (D and H above), record the maximum value (format is N5.1). For nominal variables (T, C, and S above), record the code or value used.

Sampling rule number	N1	A sequential number. Within this stand, this number uniquely codes the sampling rule used.
Variable defining the probability	C3	The variable that determines the probability by which trees will be selected. FRQ = frequency, for fixed-area plots or linear (strip) plots. BAF = basal area, for a horizontal point sample. DBH = diameter at breast height, for a horizontal line sample. HSQ = square of height, for a vertical point sample. HTS = height, for a vertical line sample.
Expansion factor	N9.4	The expansion factor, corresponding to the sampling rule above, is used to convert tree data to a per-unit-area basis (acres or hectares). For FRQ, the expansion factor is the inverse of the plot or strip area (1/plot area). For BAF, the expansion factor equals the basal area factor (BAF). For DBH, the expansion factor equals the horizontal line factor (HLF). For HSQ, the expansion factor equals the vertical point factor (VPF). For HTS, the expansion factor equals the vertical line factor (VLF).
Total number of samples	N2	Total number of plots used to sample this subpopulation. Record the total number of plots (inclusive) within the stand having a similar sampling design.
Unit of measure	C1	M = metric, E = English. All fields, on all records for this stand, must use the same unit of measure (all English or all metric).

Two examples, both corresponding to figures 1 and 2, illustrate how the sampling design fields are to be completed.

Example One—Installation number 478 contains two stands (fig. 1 illustrates plot configuration). Each stand is approximately 3 acres in size. The treatment applied to Stand 1 resulted in a 10-foot spacing, and the treatment applied to Stand 2 resulted in a 20-foot spacing. Three sample plots were randomly placed within each stand. Each plot is one-fifth acre in size, and contains a 1/300-acre subplot. Within the one-fifth acre plot, all trees greater than or equal to 1.5 inches d.b.h. were measured. Within the 1/300-acre plot, all trees less than or equal to 1.4 inches d.b.h. were measured.

Stand	Plot	Sub-plot	Sub-pop	1st char.	Min.	Max.	Rule	Var. def. probability	Expan. factor	Samples	Unit of measure
1	0	0	1	D	1.5	99.9	1	FRQ	5.0	3	E
1	0	0	2	D	0.1	1.4	2	FRQ	300.0	3	E
2	0	0	1	D	1.5	99.9	1	FRQ	5.0	3	E
2	0	0	2	D	0.1	1.4	2	FRQ	300.0	3	E

Example Two—Installation 520 contains eight stands (fig. 2 illustrates plot configuration). Each stand is slightly larger than one-fifth acre in size. Each stand contains one plot, one-fifth acre in size, and a 66-foot plot buffer. Each stand received one of four possible treatments (no treatment, 10-, 15-, or 20-foot spacing). Within each plot all trees greater than 0.6 inches d.b.h. were measured.

Stand	Plot	Sub-plot	Sub-pop	1st char.	Min.	Max.	Rule	Var. def. probability	Expan. factor	Samples	Unit of measure
1	0	0	1	D	0.6	99.9	1	FRQ	5.0	1	E
2	0	0	1	D	0.6	99.9	1	FRQ	5.0	1	E
3	0	0	1	D	0.6	99.9	1	FRQ	5.0	1	E
4	0	0	1	D	0.6	99.9	1	FRQ	5.0	1	E
5	0	0	1	D	0.6	99.9	1	FRQ	5.0	1	E
6	0	0	1	D	0.6	99.9	1	FRQ	5.0	1	E
7	0	0	1	D	0.6	99.9	1	FRQ	5.0	1	E
8	0	0	1	D	0.6	99.9	1	FRQ	5.0	1	E

If the design changed in a subsequent measurement to include only trees greater than 3.0 inches d.b.h., an additional record for each stand listed above would be completed as follows:

Stand	Plot	Sub-plot	Sub-pop	1st char.	Min.	Max.	Rule	Var. def. probability	Expan. factor	Samples	Unit of measure
1	0	0	2	D	3.0	99.9	1	FRQ	5.0	1	E
2	0	0	2	D	3.0	99.9	1	FRQ	5.0	1	E
3	0	0	2	D	3.0	99.9	1	FRQ	5.0	1	E
4	0	0	2	D	3.0	99.9	1	FRQ	5.0	1	E
5	0	0	2	D	3.0	99.9	1	FRQ	5.0	1	E
6	0	0	2	D	3.0	99.9	1	FRQ	5.0	1	E
7	0	0	2	D	3.0	99.9	1	FRQ	5.0	1	E
8	0	0	2	D	3.0	99.9	1	FRQ	5.0	1	E

Note that only the subpopulation definition changed (minimum d.b.h. from 0.6 inches to 3.0 inches); the sampling rule remained the same (one 1/5-acre plot). Fields in the plot descriptors record (record type 310) will also have to be updated to reflect the change in sampling design.

210. Administrative Descriptors

The administrative descriptors record provides a means to identify stands by project name, installation name, administrative organization, or land ownership. Two user-defined fields document project name and installation name. Because these fields are used to retrieve all information for stands or plots installed under a specific project or installation name, it is important to be consistent when completing these fields. Two additional fields code the data administrator and owner. One record is completed for each stand.

Field name	Format	Description
Source	N2	
Installation	N4	
Stand	N2	
Plot	N4	Always zero.
Subplot	N2	Always zero.
Record type	N3	210.
Project name	C25	Defined by the organization. Project names need to be consistent when they apply to more than one stand. This name is used to retrieve information for all plots installed under the same project.
Stand name	C25	Defined by the organization. The stand name can be a number and/or common name used by the organization for stand identification.
Stand administrator	C3	The organization responsible for the maintenance of the stand. Use the organization codes listed below.
Stand owner	C3	The landowner for the stand. Use the organization codes listed below. Additional codes may be added for organizations not listed here.

Organization codes:

- BCE – Boise Cascade, eastern Washington region
- BIA – Bureau of Indian Affairs (Portland)
- BLM – Bureau of Land Management
- CIT – Champion International, Timberlands
- COT – Colville Tribe
- FHT – Flathead Tribe
- FS1 – USDA Forest Service, Region 1
- IDL – Idaho Department of Lands
- IEP – Inland Empire Paper Company
- IBS – Intermountain Research Station (Boise)
- IBZ – Intermountain Research Station (Bozeman)
- IMO – Intermountain Research Station (Moscow)
- IMI – Intermountain Research Station (Missoula)
- MOF – British Columbia Ministry of Forests
- MSL – Montana Department of State Lands
- NPT – Nez Perce Tribe
- PBT – Port Blakely Tree Farms
- POT – Potlatch Corporation
- PVT – Private (small private)
- TNC – Tree Nutrition Cooperative (University of Idaho)
- UAL – University of Alberta
- UBC – University of British Columbia
- UID – University of Idaho
- UMT – University of Montana
- UWA – University of Washington
- WNR – Washington Department of Natural Resources
- WSU – Washington State University

220. Location Descriptors

The location descriptors record documents the geographic location of a stand. Latitude/longitude or Universal Transverse Mercator (UTM) coordinates entered within this record would allow the user adequate resolution to determine stand distribution within an installation or region. The coordinate fields are sufficient in size to capture information from a geographic information system or global positioning system. In a collective database, information could by retrieved by legal description, State, or geographic coordinates. One record is completed for each stand. Record the location of the center of the stand instead of an edge. If coordinates are available at the plot level, this record-type can easily be used for individual plot locations in addition to stand-level location. Additional records may have to be defined for documenting traverse information needed to locate plots on the ground.

Field name	Format	Description
Source	N2	
Installation	N4	
Stand	N2	
Plot	N4	Always zero.
Subplot	N2	Always zero.
Record type	N3	220.
State/Province	C2	Postal Service State or Province codes (MT = Montana)
Latitude (degrees)	N3	Record degrees of latitude.
Latitude (minutes)	N2	Record minutes of latitude.
Latitude (seconds)	N5.2	Record seconds of latitude. Sufficient space is allocated to record seconds of latitude to the nearest 100th of a second.
Longitude (degrees)	N3	Record degrees of longitude.
Longitude (minutes)	N2	Record minutes of longitude.
Longitude (seconds)	N5.2	Record seconds of longitude. Sufficient space is allocated to record seconds of longitude to the nearest 100th of a second.
UTM zone	N2	Record the UTM zone.
UTM easting	N6	Record the easting in meters for the southwest corner of the UTM grid cell encompassing the stand.
UTM northing	N7	Record the northing in meters for the southwest corner of the UTM grid cell encompassing the stand.
Grid type code	N1	The grid-type code references the format to be used when reading the grid-type description (below). Record the appropriate code from the list below. No grid-types have been defined for Canada but may be added and defined as needed. 1 = United States Township Grid.
Grid-type description	C20	This field contains all of the fields that define the information needed to describe a particular grid type. The appropriate format to use for this field is designated by the grid-type code. The format for each coordinate system is described below, and is coincident with this 20-character field.

GRID TYPE DESCRIPTIONS

Grid type 1—The following fields provide a legal description for stands in most areas of the United States. These fields collectively replace the 20-character grid type description field described above.

Field name	Format	Description
Nearest forty	C4	Nearest 40-acre partition of standard 640-acre section in which the stand occurs (NENW).
Section number	C2	Two-digit section number from 01 to 36.
Range	C3	Record range number, and "E" (east) or "W" (west).
Half-range	C1	Included to accommodate some localities in Washington. Y = yes, N = no.
Township	C3	Record township number, and "N" (north) or "S" (south).
Half-township	C1	Included to accommodate some localities in Washington. Y = yes, N = no.
Base meridian	C2	Enter code for base meridian. WM = Willamette meridian (Oregon and Washington) PR = Principal meridian (Montana) BO = Boise meridian (Idaho).
Blank	C4	The remaining four columns are left blank.

310. Plot Descriptors

A basic description of plot characteristics is provided using the plot descriptors record. This record describes the current status of the plot, the units of measurement, stand origin, timber type, age, site index, the presence of buffers, and the sampling design used. Although most of the information in this record is static, it is important that it contain the most current information. A more detailed description of the population is obtained from the plot level species summary (plot summary descriptors, record type 320). One record is completed for each plot.

Within this record, timber type is defined by the combined species codes (appendix A) for the primary and secondary species. Determination of the primary and secondary species is based on the percentage of total basal area represented by the various species occupying the plot. Appendix B defines the procedure for determining the primary and secondary species.

Field name	Format	Description
Source	N2	
Installation	N4	
Stand	N2	
Plot	N4	
Subplot	N2	
Record type	N3	310.
Plot status	C1	Indicates the availability of this plot for future remeasurement, or for the collection of additional data. Record plot status for damaged plots and note the nature of the damage using comments (record type 900). A = Actively maintained, and scheduled for remeasurement. I = Inactive, but available for remeasurement (discontinued). X = Destroyed, data only available for prior measurement periods (irrecoverable).

Comment flag	C1	Calls attention to comments of possible concern to subsequent use of this plot for analysis (Y = yes, N = no). If a Y is entered in this field, the user should assume further information is available in the comment records (record type 900).
Treatment code	C4	A user-defined code indicating which stands within this installation were treated similarly. This code is useful for extracting plots that were similarly treated.
Stand origin	C1	N = natural establishment. S = artificially seeded. P = planted. G = genetically improved planted stock. F = planted with major natural fill-in. (User-defined, a suggested minimum is 25 percent by number of stems). O = other (for example, coppice).
Primary species	C2	Enter the primary species code (appendix A). See appendix B for the determination of primary species.
Secondary species	C2	Enter the secondary species code (appendix A). See appendix B for the determination of secondary species.

All ages are based on the age of the mean top-height component of the plot. Ideally, these ages are calculated from the tree data. The Society of American Foresters (1983) defines mean top-height as "the mean height of a predetermined number of the thickest stems."

Breast-height age of the primary species	N3	Average age at breast-height for the top-height component (40 largest diameter trees/acre, or 100/hectare) of the primary species.
Breast-height age of the secondary species	N3	Average age at breast-height for the top-height component (40 largest diameter trees/acre, or 100 /hectare) of the secondary species.
Total age of the primary species	N3	Average total age for the top-height component (40 largest diameter trees/acre, or 100/hectare) of the primary species.
Total age of the secondary species	N3	Average total age for the top-height component (40 largest diameter trees/acre, or 100/hectare) of the secondary species.
First site index species	C2	Specify the first species code (appendix A) used to reference site index.
Site index for first site species	N3	Average site index for the first site index species.
Reference code for first site index species	C4	See appendix C for reference codes. This code documents the author, year of publication, base age, and region for each available site index curve or equation.

Site index methodology for first site index	N1	Use the methodology codes listed below. These methodology codes document the method used to obtain mean site index for the first site index species. 0 = method unknown. 1 = calculated from site trees in the tree data file. 2 = calculated from site trees, source not defined. 3 = estimated from top-height component. 4 = estimated from overall tree height/age relationship. 5 = estimate based on the professional judgment of the recorder. 6 = estimated from the midpoint of site classes. 7 = estimate based on habitat type or bioclimatic zone.
Second site index species	C2	Specify the second species code (appendix A) used to reference site index.
Site index for second site index species	N3	Average site index for the second site index species.
Reference code for second site index species	C4	See appendix C for reference codes. This code documents the author, year of publication, base age, and region for each available site index curve or equation.
Site index methodology for second site index species	N1	Use the methodology codes listed above to document the method used to obtain mean site index for the second site index species.
Plot buffer	C1	Buffer of similar condition and treatment around plot (Y = yes, N = no).
Average width of buffer	N5.1	Record the average width of the buffer in feet, or meters and tenths.

The following fields allow for documenting the sampling design used when the plot was installed, and one change in design during subsequent remeasurements. Additional changes in design can be appended to the end of this record.

Subpopulation/ sampling rule combination used at installation	N2	Record the subpopulation/sampling-rule combination from the sampling design record (record type 110) that corresponds to the subpopulation characteristics and sampling rule used when this plot was installed. Record as subpopulation number (N1) followed by the associated sampling rule number (N1).
Measurement number	N2	Record the measurement number (see record type 410) for the year this subpopulation/sampling rule combination was first used (year plot was installed).
First change in the initial sampling design	N2	Record the subpopulation-sampling rule combination from the sampling design record (record type 110) corresponding to the subpopulation characteristics and sampling rule used when the sampling design changed. Record as subpopulation number (N1) followed by the associated sampling rule number (N1).
Measurement number for first change in sampling design	N2	Record the measurement number (see record type 410) for the year this subpopulation/sampling rule combination was first used (year sampling design changed).

320. Plot Summary Descriptors

The plot summary descriptors record provides a per-unit-area (acres or hectares) summary of tree data recorded at the plot and species level. Sufficient information is provided to calculate estimates of relative density (Curtis 1982), stand density index (Reineke 1933), or crown competition factor (Krajicek 1961). The values for the fields in this record can be calculated from the individual tree measurements record (record type 820). Note that these calculated values are based on the subpopulation of trees sampled. One record is completed for each time the plot is measured. In addition, one record per plot per measurement is completed for each species.

Field name	Format	Description
Source	N2	
Installation	N4	
Stand	N2	
Plot	N4	
Subplot	N2	
Record type	N3	320.
Measurement number	N2	Corresponding measurement number from measurement dates record (record type 410).
Species code	C2	For a plot summary, set species code equal to 99. For a species summary, record the species code (appendix A).
Number of trees per unit area	N6	Number of trees per unit area (trees/acre or trees/ha) for this measurement.
Quadratic mean diameter	N4.1	Diameter of the tree of mean basal area, recorded to the nearest tenth of an inch (or centimeter).
Total basal area per unit area	N5.1	Total basal area per unit area (ft^2/acre or m^2/ha), to the nearest tenth of a square unit.
Top height	N5.1	The average height of the 40 largest diameter trees per acre or 100 trees per hectare, recorded to the nearest tenth of a foot (or meter).

410. Measurement Dates

The following fields document the initial and remeasurement dates for each plot, regardless of treatment. Zeros are recorded where information is not available. For analyses, the measurement interval can be calculated from these dates. It is critical that the measurement number field on other records is consistent with the corresponding measurement number information (year, month, and day) on this record. One record is completed for each year (growing season) the plot was measured.

Field name	Format	Description
Source	N2	
Installation	N4	
Stand	N2	
Plot	N4	
Subplot	N2	
Record type	N3	410.
Measurement number	N2	The sequential measurement number for this plot. The initial measurement is 1.
Measurement year	N4	Must be completed for each year the plot has been measured.
Measurement month	N2	If unknown, record a zero.
Measurement day	N2	If unknown, record a zero.

510. Treatment Descriptors

The treatment descriptors record is designed to provide a basic description of stand treatment. The term "treatment" is applied in the experimental sense to include both treated and untreated stands. A plot is still considered "treated" even if no alteration of the stand takes place (control plot). The user may choose to define additional record types to document the details of each treatment.

The proper way to document stands serving as an experimental control needs to be clearly understood. While compiling information for a large number of permanent growth and yield plots it became apparent that controls could be grouped into two categories. The first category of control stands occurred in unaltered, natural forests. The second category of control stands occurred in natural forest stands that were thinned or altered prior to establishing the study. Alteration of a forest stand was usually done to prepare a site for the application of a designed experimental treatment, such as fertilization, in which a group of unfertilized (but thinned) stands served as a control. Both categories of control stands would be traditionally coded as "untreated," but for the latter category, a user would be unaware that the stand had been altered prior to installation of the study. To distinguish between these two categories, an additional field was created to indicate whether the control treatment was being placed in a stand that had been intentionally altered prior to plot installation. By not making this distinction, a bias could be introduced when interpreting the growth response of trees from controls placed in natural stands versus altered stands.

One record is completed for each treatment the stand received. The initial treatment is treatment number one. It is possible to document treatments imposed on the stand prior to plot establishment by using *non-zero* negative numbers for treatment number.

Field name	Format	Description
Source	N2	
Installation	N4	
Stand	N2	
Plot	N4	Always zero.
Subplot	N2	Always zero.
Record type	N3	510.
Treatment number	N2	Sequential treatment number for this stand. Initial treatment number is 1. Treatments prior to plot establishment are numbered sequentially beginning with –1.
Year of treatment	N4	Must be completed for each treatment. For control stands this would be the installation year.
Month of treatment	N2	If unknown, enter zero.
Day of treatment	N2	If unknown, enter zero.
Prior stand alteration	C1	Record Y if the stand was intentionally altered prior to the establishment of the study, otherwise enter N.

Treatment class	C1	General type of treatment. Enter the most appropriate code. U = Untreated (control or natural stand). R = Regeneration system. T = Thinning or spacing control. F = Fertilization. S = Site preparation. B = Brush control. O = Other (describe in record type 900).
Treatment type	C2	The category of codes to choose from below must correspond to the treatment class code used above. Enter the most appropriate code, or leave blank if treatment class is "Other." If untreated or control (U above) UT = Untreated If regeneration system (R above) CC = Clearcut ST = Seed tree SW = Shelterwood SL = Selection (group or individual) If thinning or spacing control (T above) MH = Mechanical (hand or chainsaw) MD = Mechanical (dozer or feller-buncher) CH = Chemical If fertilization (F above) AA = Aerial application HA = Hand application If brush control (B above) CA = Chemical (aerial application) CH = Chemical (hand application) MC = Mechanical BU = Burning

610. Site Descriptors

The following fields describe general site characteristics for the plot. Fields are provided for soil site index, which is used by some agencies as an indirect estimate of a species site index when suitable site trees are not available in the stand. One record is completed for each plot.

Field name	Format	Description
Source	N2	
Installation	N4	
Stand	N2	
Plot	N4	
Subplot	N2	
Record type	N3	610.
Elevation	N5	Record in feet or meters.
Aspect	N3	Record aspect in degrees azimuth except for the following special cases. North = 360 Flat terrain = 999 Missing value = 0
Slope	N3	Record percent slope (10 for 10 percent slope) except for the following special cases. Flat terrain = 999 Missing value = 0
Position	N1	Position codes identify the relative topographic position of the plot. These codes should relate to most other coding systems in use. 1 = Flat or rounded ridge or hilltop 2 = Narrow ridge or hilltop 3 = Sidehill - upper one-third 4 = Sidehill - middle one-third 5 = Sidehill - lower one-third 6 = Draw bottom 7 = Bench or terrace (surface or ground water influenced) 8 = Broad flat, basin, or gentle terrain.
Soil site index species code	C2	Record the reference species code (appendix A) for the soil site index.
Soil site index	N3	Site index value estimated from soil, climate, and topography.
Soil site index reference code	C4	User-defined author reference code for soil site index. This code, and the appropriate reference, should be added to appendix C.

Bioclimatic zone	C30	The classification descriptor for the classification system used. Left-justify the descriptor in the field. For the States of Washington and Oregon, use the eco-class coding system and record the alphanumeric life-form and the two-digit numeric association (for example, record CWG1-12 for: the conifer climax community, white fir major climax species, pinegrass ground vegetation, and the association [12] of ABGR/CARU-ASH). For other States in the Inland Northwest, use habitat mnemonics, recorded as Series/Type-Phase (for example, PSME/PHMA-PHMA or PSME/PHMA). For British Columbia, use the biogeoclimatic classification system and record the appropriate zone/site code (for example, SBSe2/01 for the Sub-Boreal Spruce Zone [SBS], Moist Cool Central Subzone [e], Fraser Basin Variant [2], Bunchberry-Moss Site Series [01]).
Classification system	C7	This code documents the classification system used. The first five letters document the author, and the last two characters document the year the classification was published. (Example: PFIST77, for Pfister, Montana, 1977, "Habitat Types of Montana.")

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DAUBE68 = Daubenmire and Daubenmire (1968)
FRANK73 = Franklin and Dyrness (1973)
PFIST77 = Pfister and others (1977)
COOPE87 = Cooper and others (1987)
STEEL81 = Steele and others (1981)
STEEL83 = Steele and others (1983)
HALL 84 = Hall (1984)
POJAR87 = Pojar and others (1987)
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SUPPLEMENTAL INFORMATION

Supplemental records are special-purpose records that expand on information provided by the core records. Supplemental records are developed as required to meet the objectives of information exchange or plot documentation. During the development of a standardized database for the Inland Northwest Growth and Yield Cooperative, additional records were defined to document administrative units, fertilization treatments, soils, climate, and regression coefficients for height from d.b.h. regressions. Table 2 provides an overview of the currently defined supplemental records. Each record is discussed in detail on the following pages.

Table 2—Summary of the supplemental information records

Record type	Record label	Description
230	Administrative units	Forest, district, compartment, timber unit or other user-defined information. One record for each stand or plot.
520	Fertilization treatments	Nutrient source, application rate of nitrogen, phosphorus, potassium, sulfur, or micronutrient. One record for each time the stand was fertilized.
620	Soil descriptors	Soil profile description availability, physical or chemical analyses, rooting depth, texture of soil to rooting depth, coarse fragments, and drainage class. One record for each stand.
630	Climatic descriptors	Annual precipitation, growing season precipitation, mean growing season temperature, degree days, frost-free days. One record for each stand.
710	Height from d.b.h. regression	Measurement number, species code, and a description of the equation form, including coefficients. One record for each d.b.h./height regression.

230. Administrative Units

As discussed earlier, the source, installation, stand, plot, and subplot fields are used to internally reference plots across the various records described in this report. It is typical for each organization to have additional fields that provide a more familiar or descriptive identifier than the internal identifier used here. The administrative units record type was designed to provide a link between the identifier used in this report and an organization's own recordkeeping system. Suggested field descriptions are provided, but the full record, after the record-type field and up to column 80, is available to the user for defining fields applicable to their needs. One record per stand or plot.

Field name	Format	Description
Source	N2	
Installation	N4	
Stand	N2	
Plot	N4	
Subplot	N2	
Record type	N3	230.
Forest (Farm)	C5	Forest or tree farm license code used by the organization.
District	C5	District or block code used by the organization.
Compartment	C5	Compartment code used by the organization.
Timber unit (stand)	C5	Timber unit or stand code used by the organization.
Additional information	C43	Additional cross-referencing information.

520. Fertilization Treatments

The fertilization treatments record is designed to provide a very basic description of fertilization treatments. A user may have to define additional fields or records to document the details of the fertilization treatment. One record for each time the stand was fertilized.

Field name	Format	Description
Source	N2	
Installation	N4	
Stand	N2	
Plot	N4	Always zero.
Subplot	N2	Always zero.
Record type	N3	520.
Treatment number	N2	Record the corresponding treatment number from the treatment descriptors record (record type 510).
Source of nutrient	C35	Record the compound used for fertilization. User-defined.
Application rate of nitrogen	N3	Lb/acre (kg/ha) of nitrogen applied to the stand.
Application rate of phosphorus	N3	Lb/acre (kg/ha) of phosphorus applied to the stand.
Application rate of potassium	N3	Lb/acre (kg/ha) of potassium applied to the stand.
Application rate of sulfur	N3	Lb/acre (kg/ha) of sulfur applied to the stand.
Application rate of micronutrient	N3	Lb/acre (kg/ha) of micronutrient applied to the stand.

620. Soil Descriptors

The following fields provide a cursory description of information available on soils for a particular stand. One record for each stand.

Field name	Format	Description
Source	N2	
Installation	N4	
Stand	N2	
Plot	N4	Always zero.
Subplot	N2	Always zero.
Record type	N3	620.
Soil profile description available	C1	Documents the availability of a soil description for this stand from the organization. Y = yes, N = no.
Physical soil description available	C1	Documents the availability of a description of the physical characteristics of the soil for this stand from the organization. Y = yes, N = no.
Chemical soil description available	C1	Documents the availability of a description of any chemical analysis done for the soil on this stand from the organization. Y = yes, N = no.
Rooting depth	N4.1	Depth to which the bulk of fibrous roots penetrate. Record the depth where the USDA Soil Conservation Service (1975) abundance class drops from common to few for fine and medium roots.

Texture of soil to rooting depth	C4	Texture class code from the list below: SAND = sand LOSA = loamy sand SALO = sandy loam LOAM = loam SACL = sandy clay loam CLLO = clay loam SANC = sandy clay CLAY = clay SILC = silty clay SICL = silty clay loam SILO = silty loam SILT = silt FMAT = fibric material HMAT = hemic material PEAT = peat CIND = cinders VASH = andic, volcanic ash
Coarse fragments	N2	Percentage, by volume, of coarse fragments greater than 2 mm in the rooting zone.
Drainage class	N1	The drainage class codes document infiltration rates for soils. 1 = poor, 1 cm/h 2 = moderate, 5 cm/h 3 = well, 10 cm/h

630. Climatic Descriptors

The following fields generally describe the local climate. The source and accuracy of this information is not defined or documented. One record per stand.

Field name	Format	Description
Source	N2	
Installation	N4	
Stand	N2	
Plot	N4	Always zero.
Subplot	N2	Always zero.
Record type	N3	630.
Annual precipitation	N3	Total annual precipitation.
Growing season precipitation	N3	Total precipitation for the growing season.
Mean growing season temperature	N3	Average temperature for the growing season.
Degree days	N5	The cumulative degree days above which growth of a species can be initiated and maintained.
Frost-free days	N3	Average number of consecutive frost-free days per year (frost-free season).

710. Height From D.b.h. Regression

The height from d.b.h. regression coefficients are calculated from the tree data file. This record provides a means to capture those coefficients and the appropriate equation form. One record for each d.b.h./height regression.

Field name	Format	Description
Source	N2	
Installation	N4	
Stand	N2	
Plot	N4	
Subplot	N2	
Record type	N3	710.
Measurement number	N2	Corresponding measurement number from record type 410 (Measurement dates). If the equation is developed from data pooled across remeasurements, record 0.
Species code	C2	See appendix A for species code.
Continuation number	N1	This code allows for continuing longer equation records. First record is 1; additional records are numbered sequentially.
Equation form	C55	Document equation, including coefficients, using ANSI (1978) FORTRAN-77 standard functions. For example: –2.113 + (6.288*DBH) – (0.090*(DBH**2)) is recorded for the equation: total height = $-2.113 + 6.288$ d.b.h. $- 0.090$ d.b.h.^{2}.

INDIVIDUAL TREE INFORMATION

Individual tree measurements and history are the essential core of long-term growth and yield plots. Individual tree measurements are the source of summary information detailed in other records. Proper data interpretation and management dictates the necessity for individual tree records to be as complete and accurate as is reasonable, given the resources available within an organization.

Table 3 provides an overview of the currently defined individual tree records. The fields identified are those that are commonly recorded. Organizations are encouraged to expand on this basic structure and add the fields necessary to fully document and describe the tree measurements recorded. For example, the University of Montana developed a height measurement record, based on Curtis' (1983) procedures, to carry the detail for height measurements, such as clinometer angles, slope distance, and pole length. Each record is discussed in detail on the following pages.

Table 3—Summary of the individual tree records

Record type	Record label	Description
810	Individual tree descriptors	Tree number, species, age, stem-map coordinates, number of replicates, and number of measurements. One record for each tree measured.
820	Individual tree measurements	Tree number, measurement number, diameter, height, live crown, measurement precision, crown class, tree status, tree class, damage, and radial growth. One record for each year an individual tree was measured.

810. Individual Tree Descriptors

The individual tree descriptors record describes tree attributes which generally do not change over time. One record is completed for each tree in the plot. The number of measurement fields can be generated and updated from the individual tree measurements records (record-type 820). The primary key (source, installation, stand, plot, subplot) and tree number will uniquely identify data for an individual tree.

Field name	Format	Description
Source	N2	
Installation	N4	
Stand	N2	
Plot	N4	
Subplot	N2	
Record type	N3	810.
Tree number	N4	Number assigned by the organization to an individual tree.
Species code	C2	Record the two-character species code (see appendix A).
Breast-height age	N3	Record breast-height age at the first measurement (initial measurement of the tree).
Total age	N3	Record total age at the first measurement (initial measurement of the tree).
X-coordinate	N7.2	Coordinate position of this tree relative to a user-defined origin. Record X-position in tenths of feet or 100ths of meters from origin.

Y-coordinate	N7.2	Coordinate position of this tree relative to a user-defined origin. Record Y-position in tenths of feet or 100ths of meters from origin.
Bearing from plot center	N3	Record degrees azimuth from plot center to this tree. Record 360 for north. For use when X-Y coordinates are not appropriate, such as for circular plots.
Distance from plot center	N6.2	Record the horizontal distance from plot center to this tree, in tenths of feet or 100ths of meters. For use when X-Y coordinates are not appropriate, such as for circular plots.
Number of replicates	N5	Expansion factor to be used when this tree represents "n" other trees on the plot. For most plots the replicate value will be 1. Record the number of trees per plot represented by this tree number.
Number of measurements	N2	Number of measurement records for this tree. This value corresponds to the total number of measurement records (record type 820) recorded for this tree.

820. Individual Tree Measurements

The following list describes individual tree attributes recorded at each measurement. The primary key (source, installation, stand, plot, subplot), in addition to tree number and measurement number, will uniquely identify a single measurement for any tree. One record is completed for each year an individual tree is measured.

Field name	Format	Description
Source	N2	
Installation	N4	
Stand	N2	
Plot	N4	
Subplot	N2	
Record type	N3	820.
Tree number	N4	Number assigned by the organization to an individual tree.
Measurement number	N2	This number corresponds to the measurement number recorded for this measurement on record type 410.
Diameter at breast height	N5.1	Diameter at breast-height (d.b.h.) in inches or centimeters.
Diameter-measurement precision code	N1	Code the d.b.h. measurement precision. 0 = not directly observed or tree has not reached breast height (or not one of the other codes listed) 1 = ±0.1 inch (D-tape or caliper) 2 = ±1 inch (Biltmore stick) 3 = ±2 inches (ocular estimate to 2-inch class) Codes 4-8 reserved for future use 9 = estimate calculated from previous and subsequent d.b.h. measurements

Total height	N6.2	Total height in feet or meters.
Height-measurement precision code	N1	Code the height-measurement precision. 0 = not directly observed or not one of the other codes listed 1 = ±0.1 feet (transit) 2 = ±0.5 feet (telescoping height pole) 3 = ±1 foot (clinometer, Abney level, Haga altimeter) Codes 4-6 reserved for future use 7 = ocular estimate in the field 8 = estimate calculated from height from d.b.h. regression equation 9 = estimate calculated from previous and subsequent height measurements
Percent live crown	N3	Percentage of total height in live crown in whole units. Use a comment record to document the definition of the base of the live crown.
Live crown precision code	N1	Code the measurement precision for percentage of live crown. 0 = not directly observed 2 = ±1 percent (measured heights with clinometer, etc.) 6 = ±5 percent (ocular estimate)
Crown class	N1	Crown class code. See appendix D.
Tree status	N1	Tree status code. See appendix D.
Tree class	N1	Tree class code. See appendix D.
First tree condition	N2	First tree condition code. See appendix E.
Severity of damage 1	N1	Severity of damage associated with the first tree condition code. See appendix F.
Location of damage 1	N1	Location of damage associated with the first tree condition code. See appendix F.
Second tree condition	N2	Second tree condition code. See appendix E.
Severity of damage 2	N1	Severity of damage associated with the second tree condition code. See appendix F.
Location of damage 2	N1	Location of damage associated with the second tree condition code. See appendix F.
Third tree condition	N2	Third tree condition code. See appendix E.
Severity of damage 3	N1	Severity of damage associated with the third tree condition code. See appendix F.
Location of damage 3	N1	Location of damage associated with the third tree condition code. See appendix F.
Radial-growth increment	N4.2	Radial growth from increment cores recorded for the interval length documented below. For example, a 1-inch radial increase for a 10-year period is recorded as 1.00.
Radial-growth interval	N2	Record the measurement interval (number of years) represented by the radial-growth increment recorded above.

COMMENTS

900. Comment Card

The following fields provide a means for recording any information that would be helpful to the user in interpreting plot information. These fields are useful for documenting the overall purpose, objective, and characteristics of an installation, stand, plot, or subplot.

Field name	Format	Description
Source	N2	
Installation	N4	
Stand	N2	
Plot	N4	
Subplot	N2	
Record type	N3	900.
Continuation number	N2	Numerical sequence of the comment card within an installation, stand, plot, or subplot.
Blank	C1	One column is left blank before comments to improve readability.
Comments	C60	General comments for any installation, stand, plot, or subplot. The comments for each level are "keyed" by using the installation, stand, plot, and subplot codes. For example, to define comments at the installation level record the installation number; and set stand, plot, and subplot to zero.

910. Individual Tree Comment Card

The following fields provide a means for recording any information that would be helpful to the user in interpreting individual tree information. These fields are useful for documenting any unique characteristics about the measurement of a specific tree.

Field name	Format	Description
Source	N2	
Installation	N4	
Stand	N2	
Plot	N4	
Subplot	N2	
Record type	N3	910.
Tree number	N4	
Measurement number	N2	
Continuation number	N2	Numerical sequence of the individual tree comment card for an individual tree.
Blank	C1	One column is left blank before comments to improve readability.
Comments	C50	General comments for an individual tree at a particular measurement.

CONCLUSIONS

The data fields and formats presented here have been tested against a large number of growth and yield plots being maintained by the University of Montana and the Intermountain Research Station's Forestry Sciences Laboratory at Moscow, ID. Given the diversity of growth and yield information, standard definitions and formats provide a means to communicate knowledge while maintaining data integrity. In addition, these definitions and data formats can be extracted and referenced for other types of data processing and data collection, such as forest inventory or formal research projects. Although the data structure presented here is flexible enough to accommodate new types of information, an attempt has been made to identify information basic to interpreting, understanding, and documenting growth and yield plot data. Whether or not these formats are fully adopted by an organization, the formats and definitions provide the building blocks for sound data management.

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APPENDIX A: SPECIES CODES

Standard alpha species codes. The INGY codes are mostly similar to COSMADS codes (Arney and Curtis 1977), with some extensions.

INGY	Common name	Scientific name
DF	Douglas-fir	*Pseudotsuga menziesii*
XH	Hemlock species	*Tsuga* spp.
WH	Western hemlock	*Tsuga heterophylla*
MH	Mountain hemlock	*Tsuga mertensiana*
XS	Spruce species	*Picea* spp.
ES	Engelmann spruce	*Picea engelmannii*
XL	Larch species	*Larix* spp.
AL	Subalpine larch	*Larix lyallii*
WL	Western larch	*Larix occidentalis*
XF	True fir species	*Abies* spp.
AF	Subalpine fir	*Abies lasiocarpa*
GF	Grand fir	*Abies grandis*
NF	Noble fir	*Abies procera*
SF	Pacific silver fir	*Abies amabilis*
XC	Cedar species	*Thuja* spp.
RC	Western redcedar	*Thuja plicata*
XP	Pine species	*Pinus* spp.
LP	Lodgepole pine	*Pinus contorta*
PP	Ponderosa pine	*Pinus ponderosa*
PF	Limber pine	*Pinus flexilis*
PA	Whitebark pine	*Pinus albicaulis*
WP	Western white pine	*Pinus monticola*
JP	Jack pine	*Pinus banksiana*
XJ	Juniper species	*Juniperus* spp.
PY	Pacific yew	*Taxus brevifolia*
PB	Paper birch	*Betula papyrifera*
RA	Red alder	*Alnus rubra*
MM	Mountain maple	*Acer spicatum*
BM	Big leaf maple	*Acer macrophyllum*
QA	Quaking aspen	*Populus tremuloides*
CO	Black cottonwood	*Populus trichocarpa*
BP	Balsam poplar	*Populus balsamifera*
CH	Cherry species	*Prunus* spp.
WI	Willow species	*Salix* spp.
CX	Miscellaneous conifers	
HX	Miscellaneous hardwoods	
XX	Unknown species	

APPENDIX B: DETERMINATION OF PRIMARY AND SECONDARY SPECIES

The following procedure for determining primary and secondary species (Arney and Curtis 1977) is based on plot basal area. This procedure can be adapted to areas with only regeneration by substituting percentage of total number of trees for basal area.

A. If the species with the *greatest* percentage of basal area is 80 to 100 percent of the total plot basal area.

Action: Name this species as the primary species; no secondary species is named.

B. Otherwise, if the species with the *greatest* percentage of basal area is 50 to 79 percent of the total plot basal area.

Action: Name this species as the primary species, and determine the secondary species:

1. If the species with the *second greatest* percentage of basal area is 20 percent or greater then name this species as the secondary species.
2. Otherwise, name the species group as the secondary species (CX for mixed conifers, HX for mixed hardwoods).

C. Otherwise, the species with the *greatest* percentage of basal area is less than 50 percent of the total plot basal area.

Action: Name the species group as the primary species (CX for mixed conifers, HX for mixed hardwoods), and determine the secondary species:

1. If the species with the *greatest* percentage of basal area is 20 percent or greater, then name this species as the secondary species.
2. Otherwise, no secondary species is named.

APPENDIX C: SITE INDEX CODES

Codes for available site index curves and equations. A site index species code is designated with a sequential two-digit number that is based on the date of that reference in relation to other site index references for that species.

Site- index code	Reference	Locality	Index Age
DOUGLAS-FIR:			
DF01	King (1966)	western WA	50
DF02	Brickell (1968)	western MT,ID,WY,UT,CO	50
DF03	Cochran (1979a)	eastern OR, eastern WA	50
DF04	Summerfield (1980a)	eastern WA	50
DF05	Hegyi and others (1981)	BC	50
DF06	Hegyi and others (1981)	BC	100
DF07	Monserud (1985)	northern ID, northwestern MT	50
ENGELMANN SPRUCE:			
ES01	Brickell (1966)	western MT,ID,WY,CO,UT	50
ES02	Alexander (1967)	CO, WY	100
ES03	Clendenen (1977)	CO, WY	50
GRAND FIR:			
GF01	Stage (1959)	Inland Empire	50
GF02	Brickell (1970)	Inland Empire	50
GF03	Cochran (1979b)	eastern WA, eastern OR	50
LODGEPOLE PINE:			
LP01	Alexander (1966)	CO,WY,UT,ID,MT, eastern WA, eastern OR	100
LP02	Brickell (1970)	CO,WY,UT,ID,MT, eastern WA, eastern OR	50
LP03	Kirby (1975)	Alberta	70
LP04	Hegyi and others (1981)	BC	50
LP05	Hegyi and others (1981)	BC	100
PONDEROSA PINE:			
PP01	Meyer (1938)	CA,OR,WA,ID,MT,SD	100
PP02	Lynch (1958)	northern ID, WA, MT	100
PP03	Brickell (1970)	northern ID, WA, MT	50
PP04	Barrett (1978)	eastern WA, eastern OR	100
PP05	Summerfield (1980b)	eastern WA	50
PP06	Tesch and others (1980)	western MT	50
PP07	Hegyi and others (1981)	BC	50
PP08	Hegyi and others (1981)	BC	100
WESTERN HEMLOCK:			
WH01	Barnes (1962)	western OR, western WA, western BC, AK	100
WH02	Wiley (1978)	western WA, western OR, western BC	50
WH03	Hegyi and others (1981)	BC	50
WH04	Hegyi and others (1981)	BC	100
WESTERN LARCH:			
WL01	Brickell (1970)	western MT, northern ID	50
WL02	Schmidt and others (1976)	western MT, northern ID	50
WL03	Hegyi and others (1981)	BC	50
WL04	Hegyi and others (1981)	BC	100
WESTERN WHITE PINE:			
WP01	Haig (1932)	northern ID	50
WP02	Deitschman & Green (1965)	northern ID	50
WP03	Brickell (1970)	northern ID	50
WL04	Hegyi and others (1981)	BC	50
WL05	Hegyi and others (1981)	BC	100
WESTERN RED CEDAR:			
RC01	Hegyi and others (1981)	BC	50
RC02	Hegyi and others (1981)	BC	100

APPENDIX D: CROWN CLASS, TREE STATUS, AND TREE CLASS CODES

Crown Class Codes

Enter the most applicable crown class code from the list below. The codes are from Curtis (1983) with some minor modifications.

(0) No estimate	(5) Understory
(1) Dominant	(6) Overstory
(2) Codominant	(7) Open-grown
(3) Intermediate	(8) Shrub form
(4) Suppressed	(9) Off-plot tree

Tree Status Codes

Enter the most applicable tree status code from the list below. The codes are from Curtis (1983) with some minor modifications.

(0) Live
(1) Cut
(2) Dead
(3) Code reserved for future use
(4) Code reserved for future use
(5) Code reserved for future use
(6) Code reserved for future use
(7) Both site and crop tree
(8) Site tree
(9) Crop tree

It is assumed that the tree is alive when codes 7, 8, and 9 are used.

Tree Class Codes

Enter the most applicable tree class code from the list below. The codes are from Curtis (1983) with some minor modifications.

(0) No designation
(1) Code reserved for future use
(2) Code reserved for future use
(3) Ingrowth (tree too small to be measured at previous exam)
(4) Not previously measured but not ingrowth
(5) Could not locate at this measurement; presumed to be dead
(6) Live tree with measured height not suitable for height from d.b.h. regressions
(7) Code reserved for future use
(8) Code reserved for future use
(9) Code reserved for future use

APPENDIX E: TREE CONDITION (DAMAGE) CODES

The tree condition codes are hierarchical. The code is a two-digit numeric code. The first number is the generalized tree condition category. This first number is followed by a second number representing one of the subcodes from the group. For example, unknown treatment damage is recorded as "10". This coding system could easily be expanded to a third level with even more specific information. The basis for these codes is Curtis (1983). His original system was modified slightly to reflect additional damage codes that are important in the Intermountain Northwest.

Record type 820 (Individual tree measurements) allows the user to record up to three tree condition codes per tree, with the associated severity and location of damage codes (appendix F) for each tree condition code. Many times a tree has more than one type of damage but it is difficult to prioritize the damage. It is not necessary to assign tree conditions codes with any priority.

(0) No damage

(1) Treatment damage
- (0) Unknown or unspecified damage
- (1) Logging (basal wounds or top damage)
- (2) Foliar treatments (broadcast chemical)
- (3) Stem treatments (spot chemical)
- (4) Root or soil treatments
- (5) Pruning

(2) Crown diseases
- (0) Unknown or unspecified crown disease
- (1) Unhealthy appearance
- (2) Mistletoe
- (3) Needle rusts

(3) Stem diseases
- (0) Unknown or unspecified stem disease
- (1) Stem decays
- (4) Stem rusts
- (7) Stem cankers

(4) Root diseases
- (0) Unknown or unspecified root disease
- (1) *Armillaria mellea*
- (2) *Phellinus weirii*

(5) Insects
- (0) Unknown or unspecified
- (1) Defoliators
- (4) Bark beetles

(6) Animals
- (0) Unknown or unspecified
- (1) Deer or elk
- (2) Bear
- (3) Livestock
- (4) Porcupine
- (5) Mountain beaver
- (6) Other small mammals
- (7) Birds

(7) Weather
- (0) Unspecified
- (1) Windthrow, stem breakage, or down tree
- (2) Snow or ice (bending, breakage, or bole cracks)
- (3) Freezing
- (4) Moisture deficiency (drought or heat caused)
- (5) Winter dessication (red belt)
- (6) Sunscald
- (7) Lightning

(8) Physical defects
- (0) Unspecified
- (1) Broken or missing top
- (2) Dead top
- (3) Forked tree
- (4) Multiple tops
- (5) Leaning or bent tree
- (6) Crook or sweep
- (7) Checks or bole cracks
- (8) Epicormic branching

(9) General categories and miscellaneous
- (0) Unknown or unspecified damage
- (1) Suppression
- (2) Fire
- (3) Disease (unknown or unspecified)

APPENDIX F: SEVERITY AND LOCATION OF DAMAGE

Severity of Damage

The severity of damage codes are applicable only if a tree condition code or location of damage code has been specified. In general, severity is directly proportional to the amount of damage done to any single component of the tree. This component can be identified by using the location of damage codes and/or the tree condition codes. These severity of damage codes combine the coding schemes provided by Arney and Curtis (1977) and Curtis (1983), with some minor modifications.

(0) Unspecified
(1) 0 to 20 percent of component damaged
(2) 21 to 40 percent of component damaged
(3) 41 to 60 percent of component damaged
(4) 61 to 80 percent of component damaged
(5) 81 to 100 percent of component damaged

The following codes are more specific since these tree condition codes do not lend themselves to a severity index scaled in percent.

Leaning or bent tree (corresponding tree condition code: 85)
(1) <25-degree angle
(2) 26-45 degree angle
(3) >45-degree angle
(4) down tree

Broken top, dead top, or forked tree (corresponding tree condition codes: 81, 82, or 83)

(1) Forked below breast height
(2) Forked above breast height, but below first 17 feet (5.2 m)
(3) Forked top
(4) Dead or broken top with no new leader from a lateral branch (single dead or broken top)
(5) Dead or broken top with new leader from a lateral branch

Location of Damage

The location of damage codes allow for designating where on the tree the damage has occurred, if recorded. This location code corresponds to the tree condition code entered from appendix E. These codes are from Curtis (1983).

(0) No damage or no information
(1) Damage present, location unspecified
(2) Top damage
(3) Foliar (crown) damage
(4) Limb damage
(5) Bole damage other than top or basal
(6) Basal
(7) Roots

APPENDIX G: COMPARISON TO OTHER STANDARDIZED FORMATS

The following table summarizes the field formats for the data structure presented in this report, titled as the "INGY format", the U.S. version of the COSMADS formats (Hegyi 1985), and PNW's PDMS System (Curtis and Clendenen 1981). Given slight differences in definitions of some fields, every attempt was made to present a legitimate comparison.

Field name	INGY Format	U.S. COSMADS Format	PNW PDMS Format
Plot identification:			
Source	N2	—	—
Installation	N4	N3	N4
Stand	N2	—	—
Plot	N4	N4	N4
Subplot	N2	—	N2
110. Sampling design:			
Subpopulation number	N1	—	—
1st characteristic	C1	—	—
Min. limit for 1st char.	C5	—	N3
Max. limit for 1st char.	C5	—	—
2nd characteristic	C1	—	—
Min. limit for 2nd char.	C5	—	—
Max. limit for 2nd char.	C5	—	—
Sampling rule number	N1	—	—
Var. defining probability	C3	—	—
Expansion factor	N9.4	N5.4	N5
Total number of samples	N2	—	—
Unit of measure	C1	—	C1
Number of prism points	—	—	N2
Basal area factor	—	—	N3
Number of concentric plots	—	—	N1
Area of each concentric plot	—	—	N5
210. Administrative descriptors			
Project name	C25	C4	C4
Stand name	C25	C14	—
Stand administrator	C3	—	C3
Stand owner	C3	C3	C3
Common name of study	—	—	C10
220. Location descriptors			
State/Province	C2	C2	C2
Latitude (degrees)	N3	N3	N3
Latitude (minutes)	N2	N2	N2
Latitude (seconds)	N5.2	—	—
Longitude (degrees)	N3	N3	N3
Longitude (minutes)	N2	N2	N2
Longitude (seconds)	N5.2	—	—
UTM zone	N2	—	C2
UTM easting	N6	—	C6
UTM northing	N7	—	C7
Grid type code	N1	—	C4
Grid type description	C20	—	C20

Field name	INGY Format	U.S. COSMADS Format	PNW PDMS Format
Grid type 1 (U.S.)			
Nearest forty	C4	C4	C4
Section number	C2	N2	C2
Range	C3	C3	C3
Half-range	C1	—	C1
Township	C3	C3	C3
Half-township	C1	—	C1
Base meridian	C2	—	C2
310. Plot descriptors			
Plot status	C1	C1	C1
Comment flag	C1	N1	—
Treatment code	C4	C2	N1
Stand origin	C1	C1	C1
Primary species	C2	C2	N3
Secondary species	C2	C2	N3
Breast-height age, primary	N3	N3	N3
Breast-height age, secondary	N3	—	N3
Total age, primary	N3	N3	N3
Total age, secondary	N3	—	N3
1st site index species	C2	—	N3
Site index for 1st species	N3	N3	N3
Reference for 1st species	C4	C1	C2
Methodology, 1st species	N1	—	—
2nd site index species	C2	—	N3
Site index for 2nd species	N3	—	N3
Reference for 2nd species	C4	—	C2
Methodology, 2nd species	N1	—	—
Plot buffer	C1	—	—
Average width of buffer	N5.1	—	—
Subpopulation/sampling rule	N2	—	—
Measurement number	N2	—	—
1st change in sampling design	N2	—	—
Measurement no. for change	N2	—	—
Plot shape	—	C2	C2
Stem map	—	C1	C1
320. Plot summary descriptors			
Measurement number	N2	—	—
Species code	C2	—	—
Trees/unit area	N6	—	N4
Quadratic mean diameter	N4.1	—	—
Total basal area/unit area	N5.1	—	—
Top height	N5.1	—	—
410. Measurement dates			
Measurement number	N2	—	—
Measurement year	N4	N2	—
Measurement month	N2	N2	—
Measurement day	N2	N2	—
Measurement date	—	—	C8

Field name	INGY Format	U.S. COSMADS Format	PNW PDMS Format
510. Treatment descriptors			
Treatment number	N2	—	—
Year of treatment	N4	N2	—
Month of treatment	N2	N2	—
Day of treatment	N2	N2	—
Prior stand alteration	C1	—	—
Treatment class	C1	—	—
Treatment type	C2	—	N2
Chemical brush type	—	—	C1
Method of thinning	—	—	C1
Method of brush control	—	—	C1
610. Site descriptors			
Elevation	N5	N2	N4
Aspect	N3	N3	N3
Slope	N3	N3	N3
Position	N1	N1	N1
Soil site index species	C2	—	—
Soil site index	N3	—	—
Soil site index reference	C4	—	—
Bioclimatic zone	C30	—	C14
Classification system	C7	—	C1
Blocking ridge data	—	—	C1
230. Administrative units			
Forest (Farm)	C5	—	—
District	C5	—	—
Compartment	C5	—	—
Timber unit (stand)	C5	—	—
Additional information	C43	—	—
520. Fertilization treatments			
Treatment number	N2	—	—
Source of nutrient	C35	—	N1
Application rate of N	N3	N3	N3
Application rate of P	N3	N3	N3
Application rate of K	N3	N3	N3
Application rate of S	N3	N3	N3
Application of micronutrients	N3	N3	N3
Fertilization method	—	—	C1
620. Soil Descriptors			
Soil profile description	C1	—	C1
Physical soil description	C1	—	C1
Chemical soil description	C1	—	C1
Rooting depth	N4.1	N2	N3
Texture of soil	C4	—	C4
Coarse fragments	N2	—	N2
Drainage class	N1	—	N1
Soil series	—	—	C12

Field name	INGY Format	U.S. COSMADS Format	PNW PDMS Format
630. Climatic descriptors			
Annual precipitation	N3	N3	N3
Growing season precipitation	N3	N3	N3
Mean growing season temp.	N3	N3	N3
Degree days	N5	N5	N4
Frost-free days	N3	N3	N3
Solar radiation	—	N4	—
Evapotranspiration deficit	—	N4	—
Classification year	—	N2	—
Classification month	—	N2	—
Classification day	—	N2	—
710. Height from d.b.h. regression			
Measurement number	N2	—	—
Species code	C2	—	—
Continuation number	N1	—	—
Equation form	C55	—	—
810. Individual tree descriptors			
Tree number	N4	N4	N4
Species code	C2	C2	N3
Breast-height age	N3	N3	N3
Total age	N3	—	—
X-coordinate	N7.2	N4.1	N4
Y-coordinate	N7.2	N4.1	N4
Bearing from plot center	N3	—	—
Distance from plot center	N6.2	—	—
Number of replicates	N5	—	N4
Number of measurements	N2	N2	N2
Age precision code	—	—	N1
820. Individual tree measurements			
Tree number	N4	N4	N4
Measurement number	N2	N2	—
Diameter at breast-height	N5.1	N4.2	N4
Diameter precision code	N1	—	N1
Total height	N6.2	N4.1	N4
Height precision code	N1	—	N1
Percent live crown	N3	—	—
Live crown precision code	N1	—	N1
Crown class	N1	N1	N1
Tree status	N1	N1	N1
Tree class	N1	N1	N1
Tree condition code 1	N2	N1	N2
Severity of damage code 1	N1	—	N1
Location of damage code 1	N1	—	N1
Tree condition code 2	N2	—	—
Severity of damage code 2	N1	—	—
Location of damage code 2	N1	—	—
Tree condition code 3	N2	—	—

Field name	INGY Format	U.S. COSMADS Format	PNW PDMS Format
820. Individual tree measurements (Con.)			
Severity of damage code 3	N1	—	—
Location of damage code 3	N1	—	—
Radial-growth increment	N4.2	—	—
Radial-growth interval	N2	—	—
Height to live crown	—	N3	N3
Volume	—	—	N4
900. Comments			
Continuation number	N2	N1	N2
(Blank)	C1	—	—
Comments	C60	C70	C65
910. Individual Tree Comments			
Tree Number	N4	—	—
Measurement Number	N2	—	—
Continuation Number	N2	—	—
(Blank)	C1	—	—
Comments	C50	—	—
Physical soil description			
Soil depth for forest floor	—	N2	—
Soil depth A horizon	—	N2	—
Soil depth without rock	—	N2	—
Total soil depth	—	N2	—
Bulk density	—	N5.4	—
Surface sand percent	—	N3	—
Surface silt percent	—	N3	—
Surface clay percent	—	N3	—
Sub-surface sand percent	—	N3	—
Sub-surface silt percent	—	N3	—
Sub-surface clay percent	—	N3	—
Soil series name	—	C5	—
Landform code	—	C2	—
Parent material	—	C2	—
Soil great group	—	C3	—
Analysis location code	—	C3	—
Source	—	C16	—
Classification year	—	N2	—
Classification month	—	N2	—
Classification day	—	N2	—
Chemical soil description			
Organic matter in A horizon	—	N6	—
Nitrogen in A horizon	—	N6	—
Phosphorus in A horizon	—	N6	—
Potassium in A horizon	—	N6	—
Sulphur in A horizon	—	N6	—
Calcium in A horizon	—	N6	—
Magnesium in A horizon	—	N6	—
Nitrogen in A soil	—	N6	—
Phosphorus in soil	—	N6	—

Field name	INGY Format	U.S. COSMADS Format	PNW PDMS Format
Chemical soil description (Con.)			
Potassium in soil	—	N6	—
Sulphur in soil	—	N6	—
Calcium in soil	—	N6	—
Magnesium in soil	—	N6	—
Surface pH	—	N2.1	—
Sub-surface pH	—	N2.1	—
Stem mapping			
Stem map *y*-azimuth	—	N4	—
Post #1, *X*-coordinate	—	N4.1	—
Post #1, *Y*-coordinate	—	N4.1	—
Post #2, *X*-coordinate	—	N4.1	—
Post #2, *Y*-coordinate	—	N4.1	—
Post #3, *X*-coordinate	—	N4.1	—
Post #3, *Y*-coordinate	—	N4.1	—
Post #4, *X*-coordinate	—	N4.1	—
Post #4, *Y*-coordinate	—	N4.1	—
Circular plot radius	—	F4.1	—
Length of plot along *X*	—	F4.1	—
Length of plot along *Y*	—	F4.1	—
Type of stem mapping	—	C16	—
Year of stem mapping	—	N2	—
Month of stem mapping	—	N2	—
Day of stem mapping	—	N2	—

APPENDIX H: EXAMPLE RECORDS FROM A SAMPLE PLOT

This is an example of how various record types would be completed for installation 478, stand number 1 (see sampling design examples).

```
1 478 1  0 01101D1.5  99.9           1FRQ   5.0000 3E
1 478 1  0 01102D0.1  1.4            1FRQ 300.0000 3E
1 478 1  0 0210UM-MORP Project No. 24   Section 12 Lodgepole PineUMTUMT
1 478 1  0 0220MT 465339.001132629.90123139805196120lNESW1215WN13NNPR
1 478 1  1 0310ANCTRLNLP   50  0 54  0LP 54LP022    0     0Y 50.011 1 0 0
1 478 1  1 1310ANCTRLNLP    0  0  0  0LP 54LP022    0     0Y 17.012 1 0 0
1 478 1  2 0310ANCTRLNLP   50  0 54  0LP 54LP022    0     0Y 50.011 1 0 0
1 478 1  2 1310ANCTRLNLP    0  0  0  0LP 54LP022    0     0Y 17.012 1 0 0
1 478 1  3 0310ANCTRLNLP   50  0 54  0LP 54LP022    0     0Y 50.011 1 0 0
1 478 1  3 1310ANCTRLNLP    0  0  0  0LP 54LP022    0     0Y 17.012 1 0 0
1 478 1  1 0320 1LP   808 5.9  0.0 57.3
1 478 1  1 1320 1LP     3 1.1  0.0  0.0
1 478 1  1 0320 199   811 5.9153.9 57.3
1 478 1  2 0320 1LP   800 6.1  0.0 58.9
1 478 1  2 1320 1LP     4 1.0  0.0  0.0
1 478 1  2 0320 199   804 6.1163.2 58.9
1 478 1  3 0320 1LP   796 6.1  0.0 57.7
1 478 1  3 1320 1LP     2 1.1  0.0  0.0
1 478 1  3 0320 199   798 6.1161.9 57.7
1 478 1  1 0410 11983 915
1 478 1  1 1410 11983 915
1 478 1  2 0410 11983 915
1 478 1  2 1410 11983 915
1 478 1  3 0410 11983 917
1 478 1  3 1410 11983 917
1 478 1  0 0510 11983 9 0NUUT
1 478 1  1 0610 4120341  85    0    PSME/VACA                         PFIST77
1 478 1  1 1610 4120341  85    0    PSME/VACA                         PFIST77
1 478 1  2 0610 4140   6  95    0    PSME/VACA                         PFIST77
1 478 1  2 1610 4140   6  95    0    PSME/VACA                         PFIST77
1 478 1  3 0610 4135 35 115    0    PSME/VACA                         PFIST77
1 478 1  3 1610 4135 35 115    0    PSME/VACA                         PFIST77
1 478 1  0 0620YYN 3.0SICL152
1 478 1  0 0710 1LP14.3 + 8.6758 * DBH
1 478 1  1 0810    1LP  0  0    0.00    0.00  0  0.00    1 1
1 478 1  1 0810    2LP  0  0    0.00    0.00  0  0.00    1 1
1 478 1  1 0810    3LP  0  0    0.00    0.00  0  0.00    1 1
1 478 1  1 0810    4LP 46 53    0.00    0.00  0  0.00    1 1
1 478 1  1 0810    5LP 47 54    0.00    0.00  0  0.00    1 1
1 478 1  1 1810    1LP  0  0    0.00    0.00  0  0.00    1 1
1 478 1  1 0820    1 1  5.11 47.603 382000 000 000 0000.00 0
1 478 1  1 0820    2 1  5.31 48.103 432000 000 000 0000.00 0
1 478 1  1 0820    3 1  7.31 53.203 452000 000 000 0000.00 0
1 478 1  1 0820    4 1  6.71 54.303 582070 000 000 0000.23 5
1 478 1  1 0820    5 1  7.21 53.603 552070 000 000 0000.18 5
1 478 1  1 1820    1 1  1.11 19.203 2220068510 000 0000.00 0
1 478 1  0 0900 1 This is an example of how various record types would be
1 478 1  0 0900 2 completed for installation 478, stand number 1 (see sampling
1 478 1  0 0900 3 design examples). Only a partial tree list is shown for plot
1 478 1  0 0900 4 number 1, and subplot number 1 of plot 1.  Supplemental
1 478 1  0 0900 5 record types 230, 520, 630, and 910 were not used.
```


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Sweet, Michael D.; Byrne, John C. 1990. A standardized data structure for describing and exchanging data from remeasured growth and yield plots. Gen. Tech. Rep. INT-271. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 43 p.

Proposes standard data definitions and format to facilitate the sharing of growth and yield permanent plot data for the development, testing, and improvement of tree or stand growth models. The data structure presented provides standards for documenting sampling design, plot location and summary descriptors, measurement dates, treatments, site attributes, and individual tree characteristics. Standardized species, crown class, tree class, and tree condition codes are defined for use in the Intermountain Northwest.

KEYWORDS: data management systems, timber management, mensuration

INTERMOUNTAIN RESEARCH STATION

The Intermountain Research Station provides scientific knowledge and technology to improve management, protection, and use of the forests and rangelands of the Intermountain West. Research is designed to meet the needs of National Forest managers, Federal and State agencies, industry, academic institutions, public and private organizations, and individuals. Results of research are made available through publications, symposia, workshops, training sessions, and personal contacts.

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United States
Department of
Agriculture

Forest Service

Intermountain
Research Station

General Technical
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Streamflow Data for Undisturbed, Forested Watersheds in Central Idaho

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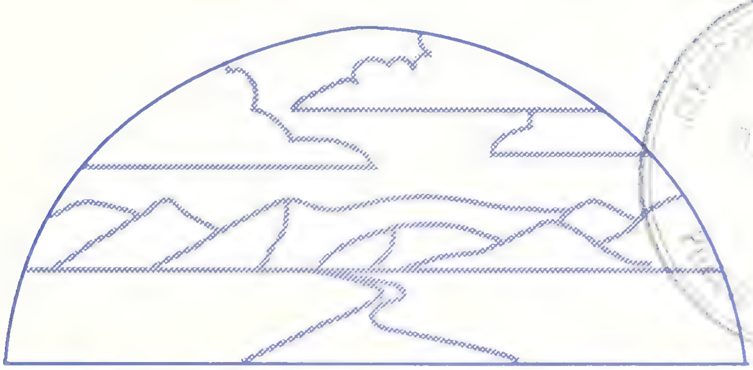

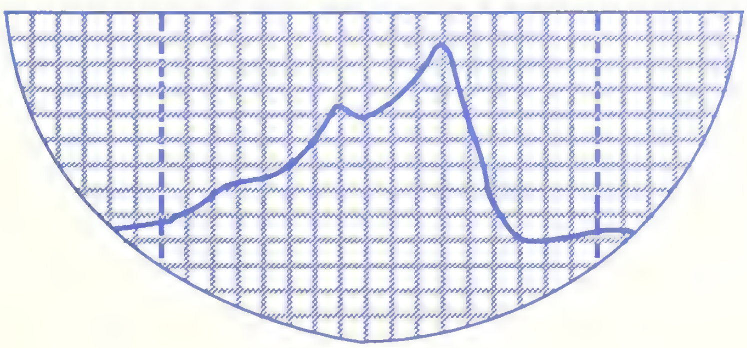

THE AUTHORS

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BUD L. JEFFERS is deceased. He was a hydrologic technician with the Intermountain Station at the Forestry Sciences Laboratory, Moscow, ID. This paper is dedicated to the memory of Bud, who was an inspiration to us all.

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CONTENTS

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INTRODUCTION

Logging activities have occurred on National Forest lands in Idaho since the early 1900's. By the mid-1950's, logging had progressed from the gentler, less erodible lands to the steeper slopes where erosion hazards are higher. This was accompanied by increasing concerns for environmental impacts. In response, the Forest Service, U.S. Department of Agriculture, initiated several administration-research studies to measure the effects of timber harvest activities on the amount, timing, and quality of streamflows in these higher erosion hazard areas. The studies are cooperative efforts between the Intermountain Research Station, National Forest System's Intermountain and Northern Regions, and the Payette, Boise, and Nez Perce National Forests.

Studies were conducted at three sites on a north-south line through the mountains of central Idaho (fig. 1). The southern and central sites are at Silver Creek and Tailholt Creek, respectively, and are representative of watersheds found in the Idaho batholith, a 16,000-square-mile area of granitic rocks in Idaho and western Montana. The northern site is in the Horse Creek drainage in the border zone geologic area just outside the Idaho batholith (fig. 1). The study sites provide a sample of a variety of topographic erosion hazards for mountain lands in the Northern Rocky Mountains ranging from moderate at the Horse Creek site to moderately high and high at the Silver Creek and Tailholt Creek sites, respectively.

Studies at all locations were designed to provide data collection for several years before any logging disturbance. These predisturbance data provide a calibration that allows us to accurately quantify the effects of subsequent timber harvest activities including tree removal and associated road construction. A total of 29 study watersheds are on the three study sites. This report and its appendix contain the mean daily streamflow and the annual summaries for all the years of predisturbance data collected on the study watersheds available through 1982. We also describe each study area and watershed and summarize the methods of data collection.

Over the years, we have received a number of requests by individuals interested in the water yield and high and low flow properties of undisturbed, forested watersheds in the Northern Rocky Mountains. Such data are rare and are included in this report to help satisfy future requests.

Figure 1—Location map of the three study sites and the Idaho batholith.

SILVER CREEK

The Silver Creek study began in 1960 as a cooperative project of the Intermountain Research Station, Intermountain Region, and the Boise National Forest to provide a test of the effects of logging on granitic parent materials. However, erosion hazards are somewhat less than in Tailholt Creek, so a variety of timber management harvest practices were proposed including tractor, skyline, and helicopter yarding plus road construction. Subsequent research findings and administrative decisions changed the ultimate logging practices to eliminate the skyline yarding and to expand the watershed level research to include a determination of changes in water chemistry in addition to evaluations of streamflow and sediment yield responses.

Site Description

The Silver Creek study area is in the southwestern Idaho batholith, 55 miles northeast of Boise in the Boise National Forest (fig. 2). The approximate center of the study area is 44°23' N. latitude and 115°47' W. longitude. The seven drainages under study (fig. 2) flow into Silver Creek, a tributary to the Middle Fork of the Payette River.

[illegible] sected and are typical of the Middle Fork Payette Canyon and Streamcut Lands Subsection, Southern Batholith Section of the Northern Rocky Physiographic Province (Arnold 1975). Slopes are relatively steep, averaging about 55 percent gradient. Elevations within the study area range from 6,820 feet at the head of the SC-1 watershed to 4,570 feet at the mouth of SC-5. Watershed SC-7 is mostly northwest facing with north and west aspects also present. Slopes on the other six drainages are oriented mostly toward the southeast, but northeast, north, and south aspects are also present. Additional features of the study drainages are summarized in table 1.

The bedrock in the Silver Creek area is primarily a medium- to coarse-grained quartz monzonite with frequent inclusions of small aplite and pegmatite dikes. The granite is moderately to well weathered (Clayton and others 1979) and decomposed to a depth of at least 6 feet.

The soils of the Silver Creek watersheds are Entisols and Inceptisols formed from the weathering of coarse-grained granitic parent material. A mosaic of four soil families is distributed within the watersheds primarily on the basis of slope and aspect (Clayton and Kennedy 1985). On southerly aspects, sandy skeletal mixed Typic Xerorthents predominate. Other aspects contain sandy skeletal mixed Typic Cryorthents, sandy skeletal mixed Cryoborolls, and mixed Alfic Cryopsamments. All soils have one or more A horizons ranging from 4 to 10 inches thick overlaying a C horizon. The dominant soil texture is a loamy coarse sand or coarse sandy loam over a gravelly coarse sand to coarse loamy sand. The soils lack cohesion due to the low silt and clay content and are extremely erodible. O horizons comprise decomposed needles and twigs and range in depth from less than 0.5 inch to over 4.5 inches. Bedrock contacts are generally shallower than 3.3 feet.

The dominant timber species are Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) and ponderosa pine

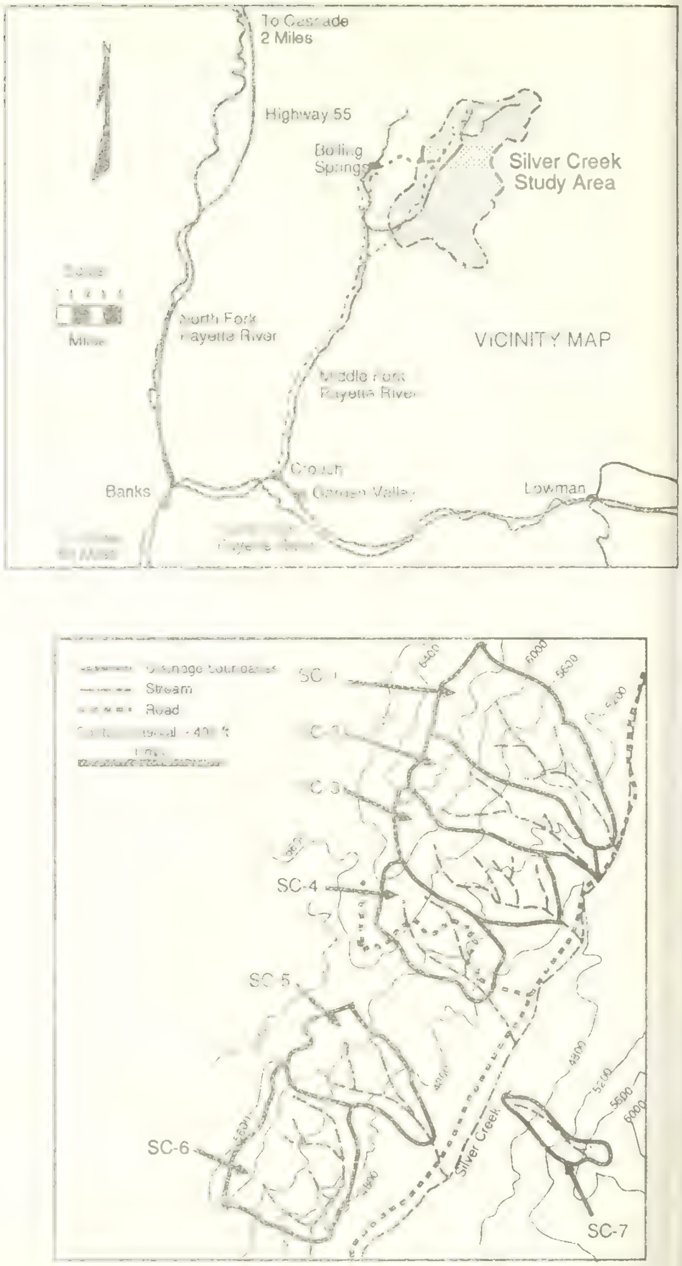

Figure 2—Location map and detail of the Silver Creek study area. Roads shown are what existed during the period of data collection.

(*Pinus ponderosa* Dougl. ex Laws.). Subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.), grand fir (*Abies grandis* [Dougl. ex D. Don] Lindl.), and Engelmann spruce (*Picea engelmannii* [Parry] Engelm.) are common in the drainage bottoms. Lodgepole pine (*Pinus contorta* Engelm.) is also present throughout much of the study area. The average basal area of the timber stands is about 115 square feet per acre except in the upper elevations of the SC-1, SC-2, and SC-3 drainages where timber stands are sparse because of wildfires in 1934 and 1949.

The records from two weather stations characterize the climate of the study area. The Upper Cabin weather station is on the ridge at the head of the SC-5 drainage at an

Table 1—Physiographic features of the drainages within the Silver Creek study area

Watershed	Area	Maximum elevation	Stream gauge elevation	Relief[1]	Relief[2] ratio	Stream order	Channel length	Drainage[3] density	Azimuth
	Mi²	*Feet*					*Miles*	*Mi⁻¹*	*Degrees*
SC-1	0.719	6,820	4,900	1,920	0.247	3	2.3	3.2	125
SC-2	.456	6,800	4,860	1,940	.252	2	1.9	4.1	121
SC-3	.497	6,600	4,750	1,850	.240	3	2.2	4.3	127
SC-4	.395	6,050	4,690	1,360	.239	2	1.5	3.8	149
SC-5	.423	5,740	4,570	1,170	.187	3	1.8	4.4	136
SC-6	.626	5,850	4,650	1,200	.185	3	3.1	4.9	142
SC-7	.089	5,970	4,650	1,320	.364	1	.5	5.6	291

[1]Relief = maximum elevation – stream gauge elevation.
[2]Relief ratio = (elevation where the extension of the main channel intersects the watershed divide – stream gauge elevation)/stream channel length extended to the watershed divide.
[3]Drainage density = channel length/area.

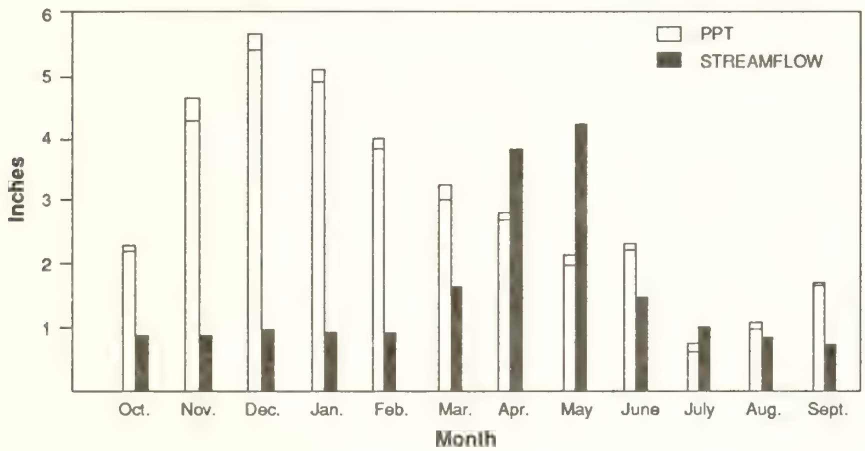

Figure 3—The average monthly distribution of precipitation for the Silver Creek Guard Station (lower bar) and Upper Cabin (upper bar) climatic stations and the average monthly distribution of streamflow for the control watershed, SC-3.

elevation of 5,520 feet, and the Guard Station weather station is near the mouth of the SC-4 drainage at an elevation of 4,660 feet. Daily temperatures ranged from highs in the mid 90's °F in the summer to lows near –20 °F in the winter. The annual averages of the daily minimum, mean, and maximum temperatures were 29.0, 40.2, and 52.5 °F, respectively.

The mean annual precipitation ranged from 35.1 inches at the Upper Cabin weather station to 34.3 inches at the Guard Station weather station. Approximately 50 to 60 percent of the precipitation fell in the form of snow with maximum snowpack depth of 50 to 60 inches (approximately 20 inches water equivalent) common at the higher weather station and 35 to 45 inches (approximately 17 inches water equivalent) common at the lower weather station.

The distribution of mean monthly precipitation for the two climatic stations in Silver Creek is shown on figure 3. Precipitation during all months of the year exceeded that on the Tailholt study area and suggests that the Tailholt area may have been influenced by a rain shadow caused by mountain terrain to the west. The general flow of air masses was similar in both the Silver Creek and Tailholt Creek study areas. Thus, monthly precipitation patterns were similar in both areas with the largest amounts occurring during winter from November through January tapering off through May. A slight increase in June led to a low in July and August followed by increasing amounts into the fall.

Streamflow

The Silver Creek study began in 1960 with the installation of a stream gauge at the mouth of the SC-5 watershed. A second stream gauge was installed at the mouth of the SC-6 watershed in 1963. Both of these original gauges were constructed by the U.S. Geological Survey (USGS) and used standard "Ogee" control sections with continuous recorders housed in 4-foot-diameter, oil cylinder stilling wells. The USGS operated the stream gauges until the

Table 2—Streamflow summaries for the Silver Creek watersheds for the record period prior to disturbance

Watershed	Period of record	Length of record	Average	Standard deviation	Range
		Years	- - - - - - - - -	Inches - - - - - - - - -	
SC-1	1965-82	18	17.48	7.34	3.71-29.07
SC-2	1965-82	18	18.31	7.74	4.86-32.29
SC-3	1965-85	21	18.21	5.94	9.19-27.19
SC-4	1965-80	16	12.05	5.68	3.27-22.86
SC-5[1]	1968-80	13	14.54	6.97	4.49-27.54
SC-6[2]	1968-76	9	14.00	6.14	6.45-24.67
SC-7	1965-76	12	16.57	8.11	7.43-30.23

[1]Additional data were collected on stream SC-5 for 1964 through 1967 by the U.S. Geological Survey and are published under the name Cabin Creek near Smiths Ferry, ID, Payette River basin, site number 13-2376.

[2]Additional data were collected on stream SC-6 for 1961 through 1967 by the U.S. Geological Survey and are published under the name Control Creek near Smiths Ferry, ID, Payette River basin, site number 13-2377.

end of the 1963 water year, at which time the Forest Service took over their operation. The original "Ogee" control sections on the SC-5 and SC-6 watersheds were replaced by Parshall flumes in 1976 and 1978, respectively. Five additional gauges were constructed by the Forest Service on the SC-1, SC-2, SC-3, SC-4, and SC-7 watersheds in 1965, all using Parshall flume control sections. Recorders installed in wooden shelters were used to obtain a continuous record of water levels at the latter five stream gauges.

Visits were made to all stream gauge sites at monthly intervals from late fall to early spring and at weekly intervals during the remainder of the year. Numerous flow measurements were made over the life of the study to check the rating equations at both the "Ogee" and the Parshall flume control sections.

Continuous records of water depth were converted to streamflow rates using the rating curves developed for the control sections at each gauge site. Data points were recorded at all slope breaks in the hydrograph and at midnight. For records from 1965 to 1974, all readings were recorded by hand then transferred to computer punchcard. From 1975 to 1985, a digitizer was used to record water depths. Flow calculations were made on a computer using Bethlahmy's (1964) integration procedure.

Streamflow data are available for the undisturbed watersheds for varying periods (table 2) depending on the schedule for timber harvest activities on each watershed. The SC-3 watershed served as the long-term control to evaluate treatment effects for the other watersheds, so data are available for the entire length of record through 1985. Similar to the Tailholt Creek study area, there was a wide range in flows between years. However, flow differences between watersheds were not as large, probably because of less variability in watershed elevations on Silver Creek. The mean annual streamflow for the SC-3 watershed was 18.2 inches, and the mean annual precipitation was 36.0 inches. Mean annual precipitation for the SC-3 watershed was calculated using the isohyetal method. The estimated annual evapotranspiration loss was therefore 17.8 inches based on the difference between the average annual precipitation and runoff values.

The mean monthly streamflow for the SC-3 watershed is shown on figure 3. The greatest flow rates occurred during the spring snowmelt, March through June. This period accounted for about 63 percent of the annual streamflow total. The maximum instantaneous flow was equally likely to occur in either April or May. Rain-on-snow events were infrequent and caused the highest annual flow rates in only 1 year (February 1968). Streamflows gradually decreased over the summer except for occasional small rises caused by high-intensity convective storms. Low flows during August, September, and October were followed by gradually increasing flows in response to fall and winter frontal storms and occasional periods of winter snowmelt.

TAILHOLT CREEK

The Tailholt Creek study began in 1959 as a component of the larger Zena Creek Logging Study, which was a cooperative effort between the Intermountain Research Station, Intermountain Region, and the Payette National Forest. The Zena Creek study was established to evaluate the utility of skyline logging systems on steep terrain in the Idaho batholith and included a broad spectrum of studies to evaluate equipment efficiencies, regeneration success, road-building techniques, and watershed impacts (Craddock 1967). Some onsite erosion studies were conducted within the Zena Creek watershed, but the major watershed management study effort was relegated to the Tailholt study area. The objective of the Tailholt study was to quantify the effects of skyline logging on streamflow rates and sediment yields. Research from Zena Creek showed that the erosional impacts of the road construction associated with skyline logging were unacceptable (Megahan and Kidd 1972), so the planned logging in Tailholt Creek was changed to a helicopter system that required no roads.

Site Description

The Tailholt study area is near the confluence of the Secesh River and the South Fork of the Salmon River in the Krassel Ranger District, Payette National Forest (fig. 4). The approximate center of the study area is 45°03' N. latitude and 115°40' W. longitude.

The study area includes two major drainages, Tailholt and Circle End, that drain directly into the South Fork of the Salmon River. These watersheds were designated as ZC-1 and ZC-2, respectively. The other three drainages are tributaries to Tailholt Creek and were designated as ZC-3, ZC-4, and ZC-5 (fig. 4).

The study area is in the Salmon River Canyonlands Subsection, Salmon Uplands Section of the Northern Rocky Mountain Physiographic Province (Arnold 1975). Slopes are steep, averaging about 65 percent, because of accelerated downcutting of the Salmon River. Elevations range from 7,760 feet at the head of ZC-3 to 3,560 feet at the mouth of ZC-2. Slope aspects extend from west through south to northeast but are predominantly southeast. Additional features of the study watersheds are summarized in table 3.

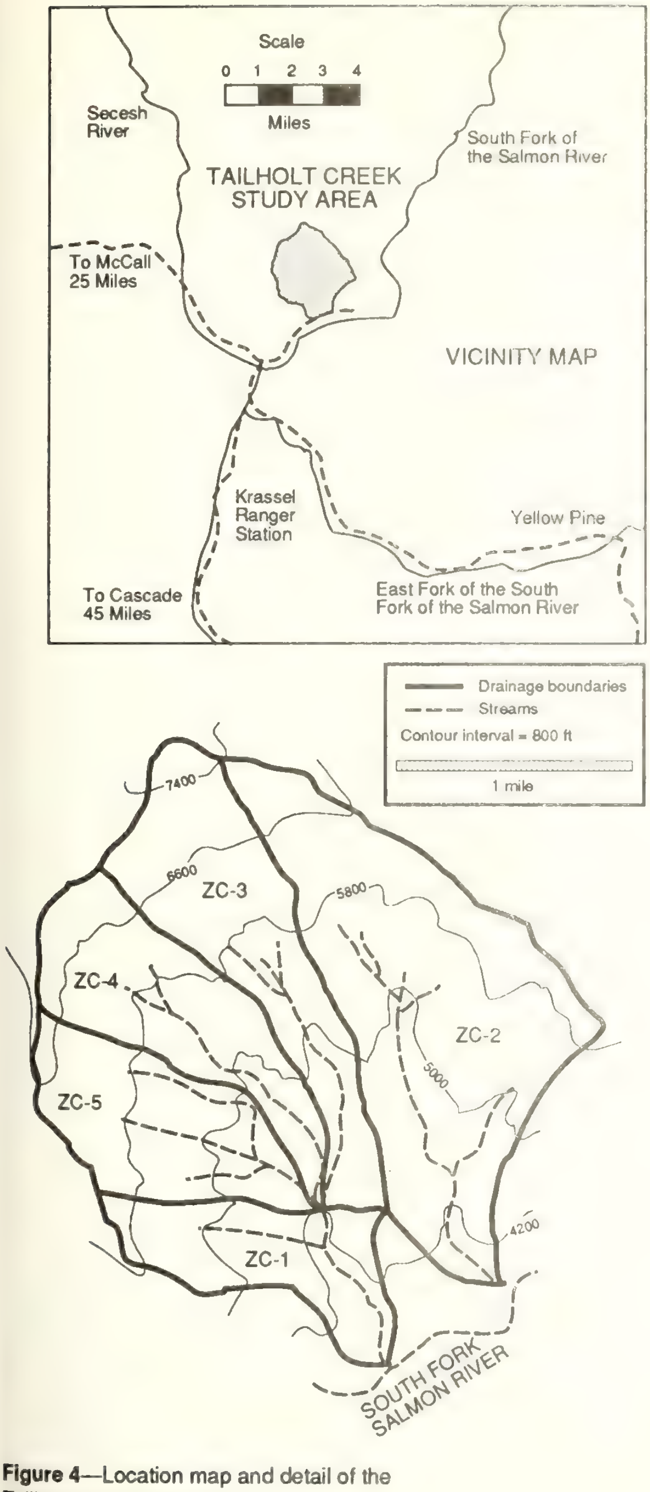

Figure 4—Location map and detail of the Tailholt Creek study area.

As is typical of much of the Idaho batholith, the bedrock in the Tailholt study area is dominantly a medium-grained quartz monzonite. Based on the classification of Clayton and others (1979), this rock is moderately fractured and weathered. Weathering progresses to a depth of at least 3 feet.

The soils in the Tailholt Creek Study Area are Inceptisols and Entisols formed from the weathering of medium- to coarse-grained granitic parent material. Eight soil families are distributed on the basis of slope, aspect, and elevation (Clayton and Larson 1969). The most extensive soil is a sandy mixed Typic Cryumbrept that usually occurs on more northerly slopes. Two other common soils are Alfic Cryopsamments (steep, southerly slopes) and Lithic Cryumbrepts (less steep, stable forested slopes). The other five soils are Lithic Cryopsamments, Lithic Xeropsamments, sandy, skeletal mixed Typic Cryorthents, and Typic Xeropsamments. All soils except the Typic Cryorthents have one or more A horizons overlaying a C horizon. The Typic Cryorthents include a B horizon. The dominant soil textures are loamy coarse sands to coarse sandy loams overlaying a loamy coarse sand to coarse sandy loam. The Typic Cryorthents typically have loamy coarse sand A and B horizons over a cobbly or gravelly loamy coarse sand. All soils lack cohesion due to low silt and clay contents and have proven to be extremely erodible following disturbance (Megahan and Kidd 1972). O horizons comprise decomposed needles and twigs and range in depth from less than 0.5 inch to over 4.5 inches. Bedrock contacts are generally less than 3.3 feet.

The dominant timber species are ponderosa pine and Douglas-fir. Subalpine fir and grand fir are common in the drainage bottoms. Whitebark pine (*Pinus albicaulis* Engelm.) is present at higher elevation, exposed locations. The average basal area for the timber stands is about 110 square feet per acre except in the ZC-2 drainage and in the head of the ZC-3 drainage where timber is patchy because of a wildfire that burned over much of the area in 1939.

The records from two storage gauges characterized the mean annual precipitation for the study area. One storage gauge was on Tailholt ridge near the head of the ZC-5 drainage at an elevation of 6,400 feet. Mean annual precipitation at this site was 36.9 inches for 1969 through 1982 (does not include 1972 through 1974). A second site was approximately 2 miles west of the study area within the Oompaul drainage at an elevation of 4,400 feet. Annual precipitation at the Oompaul gauge averaged 27.2 inches for 1968 through 1982.

A recording rain gauge is located on the divide between the ZC-1 and ZC-2 watersheds at an elevation of 4,840 feet. Records are sporadic throughout the length of the study because of difficult access. However, the records were adequate to define the variations in monthly precipitation throughout the year (fig. 5). Most precipitation occurred as snowfall from cyclonic Pacific storms during winter from November to January. Monthly precipitation decreased from January through April then increased again in May. The summer months of July, August, and early September were hot and dry except for occasional, localized, convective storms. Rainfall increased again in late September and in October as cyclonic storms from the Pacific returned to the area.

No snow survey records are available for the Tailholt study area. However, snow survey records (Soil Conservation Service, 1946-85) are available from two nearby sites: Secesh Summit at an elevation of 6,520 feet 18 miles northwest of the study site and Big Creek Summit at 6,580 feet 32 miles south. These records show that the highest winter snow water contents occurred between April 1 and May 1 and averaged approximately 36.5 inches of water.

Table 3—Physiographic features of the Tailholt Creek study area

Watershed	Area	Maximum elevation	Stream gauge elevation	Relief[1]	Relief[2] ratio	Stream order	Channel length	Drainage density[3]	Azimuth
	Mi²		*- - - - - Feet - - - - -*				*Miles*	*Mi⁻¹*	*Degrees*
ZC-1	2.539	7,760	3,600	4,160	0.259	3	6.7	2.6	136
ZC-2	1.455	7,600	3,560	4,040	.266	2	3.4	2.3	175
ZC-3	.845	7,760	4,120	3,640	.311	2	1.9	2.2	168
ZC-4	.609	7,130	4,110	3,020	.309	2	1.5	2.5	139
ZC-5	.556	6,720	4,100	2,620	.318	3	1.9	3.4	113

[1]Relief = maximum elevation – stream gauge elevation.
[2]Relief ratio = (elevation where the extension of the main channel intersects the watershed divide – stream gauge elevation)/stream channel length extended to the watershed divide.
[3]Drainage density = channel length/area.

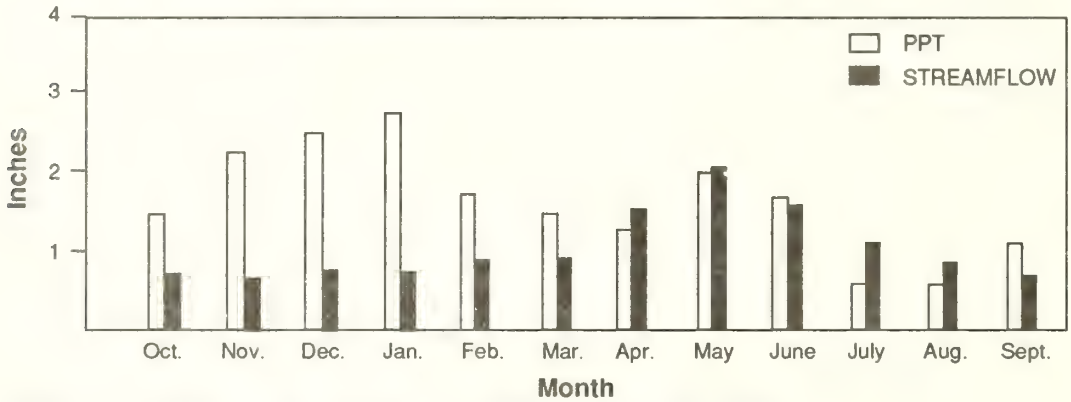

Figure 5—The average monthly distribution of precipitation for the Q12M weather station and the average monthly distribution of streamflow for the ZC-1 drainage.

South slopes below an elevation of 4,000 feet are often bare during the winter.

No temperature records are available from the study area, but temperature records were kept at the nearby town of Yellow Pine, ID, by the National Oceanic and Atmospheric Administration (1970-83). Yellow Pine is at 5,070 feet and lies 11.5 miles east of the study area. For the years 1971 to 1982 the annual averages of the daily minimum, mean, and maximum temperatures were 23.5, 39.2, and 54.6 °F, respectively (NOAA 1971-82). Temperatures commonly reached above 85 °F in the summer and often went below 0 °F in the winter.

Streamflow

Streamflow data collection began in August 1959 with the installation of a stream gauge in watershed ZC-1 by the U.S. Geological Survey (USGS). A second gauge was installed by the USGS on watershed ZC-2 in August 1962. The three additional gauges were installed by the Forest Service on watersheds ZC-3, ZC-4, and ZC-5 in August 1967. Data were collected by the USGS at the ZC-1 and ZC-2 sites through September 1962. The Forest Service continued data collection at all sites through September 1982 except at the ZC-1 and ZC-2 sites where records are missing from September 1971 to June 1974. In the fall of 1982, we decided enough data had been collected to provide a suitable calibration to evaluate timber harvest effects, and all five stream gauges were shut down. Streamflow measurements will be resumed whenever logging takes place.

Stream gauge installations at the ZC-1 and ZC-2 sites consisted of standard U.S. Geological Survey "Ogee" control sections with continuous recorders housed in 4-foot-diameter stilling wells. Stream gauges on ZC-3, ZC-4, and ZC-5 all had Parshall flume controls with continuous recorders housed in wooden shelters over 14-inch stilling wells. Stream gauges were serviced every 1 to 2 months during the spring, summer, and fall. However, remote locations and severe weather conditions made it impossible to service the gauges more than two times during the winter.

Periodic streamflow measurements were made at the "Ogee" control sections to develop a stage-discharge rating curve. Standard rating curves for Parshall flumes were used to compute flows at the ZC-3, ZC-4, and ZC-5 sites. Data points were recorded at each break in slope on the recorder strip chart along with a reading at midnight. For records from 1962 to 1971, all readings were made manually and transferred to computer punchcards.

Table 4—Streamflow summaries for the Tailholt Creek watersheds

Watershed	Period of record	Length of record	Average	Standard deviation	Range
		Years		*Inches*	
ZC-1[1]	1963-71 1975-82	17	[2]11.91	3.60	6.67-19.20
ZC-2	1963-71 1975-82	17	[2]8.16	3.33	3.83-16.85
ZC-3	1968-82	15	[3]11.34	5.00	4.40-23.11
ZC-4	1968-82	15	[3]19.74	5.65	10.76-32.21
ZC-5	1968-82	15	[4]8.61	3.08	5.57-16.33

[1]Additional data were collected on stream ZC-1 for 1960 through 1962 by the U.S. Geological Survey and are published under the name Tailholt Creek near Yellow Pine, ID, Salmon River Basin, site number 13-3138.

[2]Water years 1971 and 1975 were not included in the calculations of the average, standard deviation or range of annual streamflow.

[3]Water year 1971 was not included in the calculation of the average, standard deviation or range of annual streamflow.

[4]Water years 1971 and 1982 were not included in the calculations of the average, standard deviation or range of annual streamflow.

Records were digitized for computer analysis for 1975 through 1982. Stage height readings were converted to flow rates by computer using the integration procedure described by Bethlahmy (1964).

The annual streamflow summaries for the Tailholt watersheds are shown in table 4. The data illustrate large variations between years and between watersheds. The mean annual streamflow for ZC-1 is 11.9 inches, and the mean annual precipitation at the two storage gauge sites described above was 30.1 inches. Taking the difference between mean annual precipitation and runoff, the estimated annual evapotranspiration loss for the study area was about 18.2 inches.

The distribution of mean monthly streamflows for the ZC-1 watershed is shown on figure 5. Note that the greatest monthly discharges occurred during the spring snowmelt months of April through June. This period accounted for approximately 42 percent of the annual streamflow. Maximum instantaneous flows were also most likely to occur in the snowmelt months of March, April, or May but also occurred at any time during the late fall or winter in response to large cyclonic rain or rain-on-snow storms. For example, annual maximum peak flows occurred from rain-on-snow events in February 1968 and 1982 and in December 1978 and 1981 and from a large volume rainstorm in October 1962. Streamflows gradually decreased over the summer and fall months with occasional small rises from high-intensity, convective storms in summer and early fall, and cyclonic storms in late fall. Lowest monthly flows usually occurred in November. From December through January, monthly streamflow tended to increase slightly from winter frontal storms and snowmelt.

The daily streamflow tables for watersheds ZC-1 to ZC-5 are labeled in the appendix as Tailholt Creek Study Area, watersheds 11 to 15, respectively.

HORSE CREEK

The Horse Creek Administrative-Research Project began in 1965 in conjunction with the establishment of the Meadow Creek Barometer Watershed. This was a joint endeavor between the Northern Region, the Nez Perce National Forest, and the Intermountain Research Station.

The Barometer Watershed program established a network of representative watersheds across the Nation for the collection of hydrometeorological data to determine the impact of various management activities on the soil and water resources. The 243-square-mile Meadow Creek watershed was selected to represent the Northern Rocky Mountain physiographic Province. The Horse Creek watersheds were selected for intensive study on the effects of road construction and harvesting on streamflow and sediment production.

Site Description

The Horse Creek Administration-Research site is in Township 31 N, Ranges 8 and 9 E, Boise Meridian, in north-central Idaho. The study area occupies 7,730 acres on the Nez Perce National Forest, about 35 miles east of Grangeville, ID (fig. 6). Horse Creek flows eastwardly, entering Meadow Creek 4 miles above its confluence with the Selway River.

The area comprises two major watersheds, the East and Main Forks of Horse Creek that drain 3,561 acres and 4,169 acres, respectively (fig. 6). The East Fork is the control watershed and will remain in its present undisturbed condition. Within the Main Fork drainage are 15 gauged subwatersheds ranging in area from 54 to 364 acres. Ten subwatersheds are on the north side of the Main Fork and five on the south side. There is one control subwatershed on each side of the Main Fork, subwatersheds 6 and 27 (fig. 6).

The Horse Creek Watersheds are part of the Selway Moderately Dissected Lands Subsection of the Northern Rocky Mountain Physiographic Province (Arnold 1975). This land subsection is a dissected portion on an old erosion surface. However, Hughes (1965) stated that the eastern three-fourths of the area is in a late youth development stage, exhibiting lower drainage densities and steeper stream gradients. The western fourth of the area is part of the old erosion surface that is presently being dissected in a youthful stage. A hypsometric analysis of the East and Main Fork drainages indicates that an

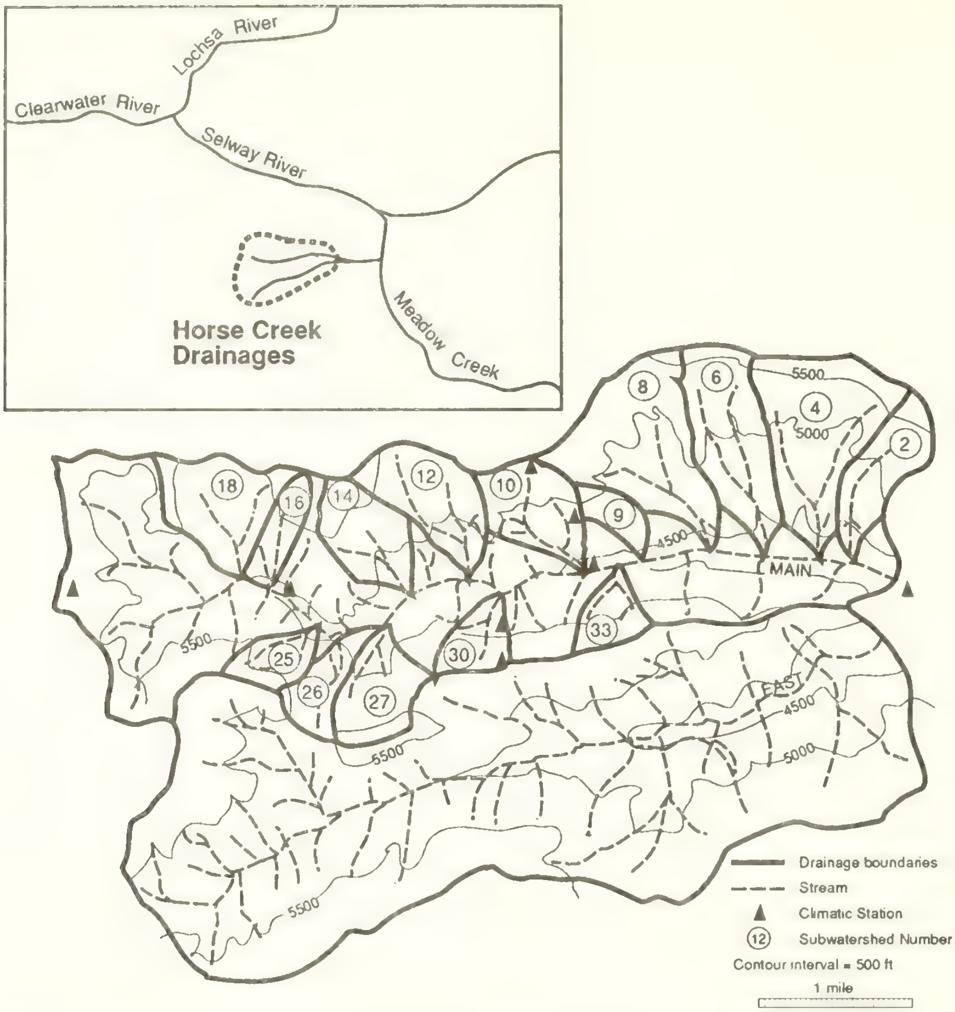

Figure 6—Location map and detail of the Horse Creek study area.

equilibrium stage has not been achieved; hence, streams are not graded, and channel downcutting and extension are dominant erosional processes.

Elevations range from 4,100 feet at the confluence of the East and Main Forks to 6,030 feet along the southern divide of the East Fork drainage. Side slopes often exceed 65 percent, especially on the lower slopes adjacent to the third order streams, but are more gentle on the middle and upper slopes and the headwaters of the East and Main Fork drainages. The median side slopes for the East and Main Fork drainages are 36 and 31 percent, respectively. The Main Fork drainage has 30 percent more of its area with a southern exposure than a northern exposure, and the East Fork drainage has 62 percent more of its area with a northern exposure than a southern exposure.

The upper slopes of Horse Creek are generally early and mid-pluvial landforms, typically with narrow ridgetops and moderate relief. Moderately frost-churned landforms are found at the higher elevations. Table 5 gives physiographic information for these 17 watersheds.

The soils in the Horse Creek watersheds are Inceptisols formed from the weathering of predominantly metasedimentary parent material and modified by deposition of loessial material of volcanic origin. The majority of the area has a mosaic of four soils, distributed partially on the basis of slope gradient and topographic position. The two most extensive soils are Andic Dystrochrepts, one coarse loamy and the other loamy skeletal. Second in extent are Typic Vitrandepts, one medial over loam and the other medial over loamy skeletal. Both skeletal soils are usually associated with ridgetop positions and the Vitrandepts with less steep landscapes. In the headwaters of the Main and East Fork drainages at elevations above about 5,000 feet are occurrences of coarse loamy, mixed, frigid Typic Haplumbrepts, usually formed under seral alder or bracken fern; coarse loamy, mixed, frigid Typic Vitrandepts formed under grand fir habitat types; and coarse loamy, mixed, Entic Cryandepts formed under subalpine fir habitat types. Aquepts occur locally in low lying portions of the landscape, adjacent to streams and in headwater areas.

The soil profile characteristics vary between soil types. However, for the complex of the two Andic Dystrochrepts and two Typic Vitrandepts, which are found over most of the watersheds, a typical soil profile has a 3.0-inch 0 horizon of partially decomposed twigs and needles.

Table 5—Selected physiographic characteristics of the 17 Horse Creek watersheds

Watershed	Area	Maximum elevation	Stream gauge elevation	Relief[1]	Relief[2] ratio	Stream order	Channel length	Drainage[3] density	Azimuth
	Mi^2	- - - - - - - - - - - *Feet*	- - - - - - - - - - -				*Miles*	*Mi^{-1}*	*Degrees*
[4]300	5.564	6,030	4,110	1,920	0.063	3	23.5	4.2	68
200	6.514	5,920	4,100	1,820	.055	3	28.0	4.3	86
202	.223	5,720	4,160	1,560	.284	1	.8	3.4	200
204	.544	5,730	4,200	1,530	.229	2	2.0	3.7	185
206	.400	5,660	4,240	1,420	.203	2	1.8	4.6	166
208	.569	5,660	4,320	1,340	.160	2	1.3	2.2	144
209	.091	5,170	4,390	780	.245	1	.5	5.1	133
210	.252	5,540	4,440	1,100	.228	2	1.4	5.5	144
212	.323	5,770	4,560	1,210	.173	2	1.4	4.3	161
214	.241	5,850	4,620	1,230	.168	2	1.1	4.4	134
216	.084	5,920	4,970	950	.263	1	.4	5.3	198
218	.333	5,920	5,000	920	.141	2	1.5	4.4	177
225	.123	5,760	4,880	880	.236	2	.7	5.4	44
226	.148	5,680	4,830	850	.161	1	.6	3.7	13
227	.262	5,680	4,680	1,000	.257	2	.8	3.2	9
230	.143	5,520	4,510	1,010	.310	2	.6	3.9	34
233	.128	5,400	4,400	1,000	.323	2	.6	4.9	358

[1]Relief = maximum elevation – stream gauge elevation.

[2]Relief ratio = (elevation where the extension of the main channel intersects the watershed divide – stream gauge elevation)/stream channel length extended to the watershed divide.

[3]Drainage density = channel length/area.

[4]Watersheds 300 and 220 are the East and Main Forks of Horse Creek, respectively.

The loessial surface layer has a loam to silt loam texture and extends to depths of 7 to 21 inches. The soil texture generally becomes coarser with depth, and the subsoil, extending to depths of 22 to 28 inches, has a loam to sandy loam texture grading to a gravelly loam to gravelly sandy loam in the skeletal soils. The substratum extends to depths of 40 to 61 inches and has a sandy loam to very gravelly sandy loam texture. The soils are well drained and have a moderately rapid to rapid permeability.

The Horse Creek watersheds are in the border zone of the Idaho batholith, a complex series of related igneous intrusions of different ages. The intrusion of magma that formed the Idaho batholith altered the adjacent rock through contact metamorphism. The majority of the parent material in Horse Creek is metamorphosed sedimentary material correlated with the Belt Super Group, tentatively classified as part of the Wallace formation. The sedimentary rock was altered by other metamorphic episodes prior to the batholith intrusions. The metasedimentary material is varied and intergrades from quartz-biotite-plagioclase gneisses and schists to biotite-plagioclase quartzites (Greenwood and Morrison 1973). The rock contains large proportions of quartz, plagioclase, biotite, and muscovite (Hughes 1965). Locally, igneous dikes and sills of granite or pegmatite occur.

The Horse Creek watersheds are timber covered with the exception of scattered occurrences of wet bottom land along the major streams and several small meadows and alder glades along the western drainage boundary. Tree species found in significant number include grand fir, western redcedar (*Thuja plicata* Donn), western larch (*Larix occidentalis* Nutt.), Engelmann spruce, and lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.). Douglas-fir (*Pseudotsuga menziesii* var. *glauca* [Beissn.] Franco) and ponderosa pine also occur on some of the south-facing slopes. The average basal area is about 150 square feet per acre with grand fir as the predominant species. In much of the area the overstory vegetation is mature and decadent. Damage to the grand fir from western spruce budworm (*Choristoneura occidentalis*) is moderate to heavy, and Indian paint fungus (*Eichinodontium tinctorium*) is prevalent. Wildfire has not played a role in stand composition for at least 150 years.

The climate of the area is influenced by both continental air masses and modified marine air masses from the Pacific Ocean. The summers are warm and relatively dry, with only a few convective storms of short duration and variable intensity. The winter months are wet and cold, although the warmer Pacific air masses can produce some winter melting of the snowpack.

In 1965, two climatic stations, consisting of hygrothermographs, weighing precipitation gauges, and anemometers, were installed at the Lower Horse and Buck Meadows sites (fig. 6) at the east and west ends of the Main Fork drainage. The Buck Meadows station is at the west end of the Main Fork drainage at an elevation of 5,600 feet. The Lower Horse station, at an elevation of 4,200 feet, is near the confluence of the East and Main Forks. The weather data from these two stations give a good representation of both the annual and elevational variation in temperature and precipitation for the area. The 20-year (1966 to 1985) average annual precipitation at the Buck Meadows station was 48.3 inches, ranging from 33.0 to 65.6 inches. At the Lower Horse station the average annual precipitation was 39.9 inches, ranging from 25.1 to 52.8 inches. Based on data from these two

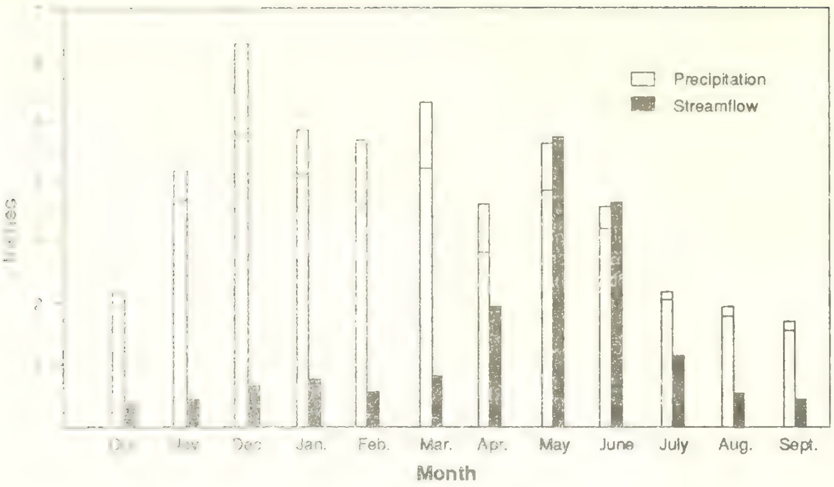

Figure 7—The average monthly distribution of precipitation for the Buck Meadows (upper bar) and Lower Horse (lower bar) climatic stations and the average monthly distribution of streamflow for the East Fork drainage.

stations, the increase in average annual precipitation with elevation was about 6 inches per 1,000 feet.

Most of the annual precipitation occurred as snowfall during the winter from December through March (fig. 7). Accordingly, the portion of the total annual precipitation occurring as snowpack averaged about 70 to 75 percent at Buck Meadows based on measurements of snow water equivalent. Precipitation was lower in April but increased somewhat during the spring rains of May. Rains decreased to a low in September before rising again as frontal systems moved into the area from the Pacific.

The average daily temperatures reached a maximum of about 60 °F in July and a minimum of 23 °F in January. Instantaneous air temperatures ranged from highs of 85 °F to as low as –20 °F.

Streamflow

In 1965, Parshall flumes and stage recorders were installed at the mouths of the East (300) and Main (200) Forks of Horse Creek, followed by the installation of H type flumes and stage recorders at the mouths of the 10 subdrainages on the north side of the Main Fork in 1974 and 1975. In 1978 H type flumes and stage recorders were installed at the five subwatersheds on the south side of the Main Fork.

From December through May the instruments were serviced every 4 to 6 weeks and every 2 weeks during the summer and fall months. Hourly stages were digitized from the recorder strip charts and converted to hourly stream discharge. The daily stream discharges presented in this report are the average of the 24 hourly stream discharges.

Table 6 summarizes the annual streamflow for these watersheds prior to any management activity. The average annual streamflow for the East Fork (300) was 17.2 inches. The average annual precipitation was about 42.9 inches. Annual evapotranspiration loss, estimated as the difference between the average annual precipitation and runoff volumes, was about 25.7 inches.

Figure 7 also displays the average monthly distribution of streamflow for the East Fork of Horse Creek. As can be seen in this example, the most significant annual hydrologic event in these watersheds was usually the spring snowmelt runoff, with about 65 percent of the streamflow occurring during April, May, and June. The maximum instantaneous flow usually occurred in May or early June and often was 30 to 50 times larger than the lowest

Table 6—Streamflow summaries for the Horse Creek watersheds for the period of record prior to any management activities

Watershed	Period of record	Length of record	Average	Standard deviation	Range
		Years	*Inches*		
200	1966-78	13	[1]20.96	7.26	11.56-30.76
202	1975-84	10	11.57	5.33	4.45-21.33
204	1975-84	10	14.97	5.99	6.11-25.64
206	1975-85	11	17.42	6.27	9.23-28.42
208	1975-78	4	20.78	8.47	9.26-29.49
209	1975-84	10	16.15	5.72	8.12-26.09
210	1975-79	5	18.83	8.13	8.66-29.09
212	1975-79	5	19.87	8.73	9.17-31.38
214	1975-79	5	20.69	9.41	9.02-32.98
216	1975-78	4	25.10	10.90	10.60-36.23
218	1975-78	4	29.76	10.75	16.04-41.95
225	1979-85	7	14.59	5.28	9.15-23.29
226	1979-85	7	15.83	5.14	11.15-25.54
227	1979-85	7	18.57	4.94	12.66-26.96
230	1979-85	7	17.57	4.47	13.04-25.32
233	1979-85	7	10.88	4.44	7.05-18.07
300	1966-85	18	[2]17.23	6.34	6.53-29.15

[1]Water years 1969-1970 were not included in the calculations of the average, standard deviation, or range of annual streamflow.
[2]Water years 1967 and 1969 were not included in the calculations of the average, standard deviation, or range of annual streamflow.

streamflow. Infrequently a rain-on-snow event in late fall or early winter occurred and, in one instance, produced the highest streamflows for that water year. Streamflows gradually decreased over the summer except for rather rapid responses to occasional convective storms. September or October was usually the month of lowest streamflow, and in the period from October through March, streamflow usually increased slightly in response to fall frontal storms and occasional periods of winter melt.

The tables for the East and Main Forks of Horse Creek are labeled in the appendix as watershed 300 and 200, respectively.

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APPENDIX: DATA LISTINGS

This appendix contains the daily, monthly, and annual discharge records for each of the 29 study watersheds. Yearly maximum and minimum instantaneous flow figures and the dates of their occurrence are also included.

Operation of streamgauges in remote, forested areas often introduces lost or inaccurate data for a variety of reasons such as obstructions in the control sections, sediment accumulations in the stilling well intake pipes, and recorder breakdowns. One of the most common problems is ice in the control sections and freezing of the stilling well intake pipes. As a result, data are most often lost during winter. For this publication, in all cases of lost or inaccurate records the missing data are estimated and the streamflow values are so indicated. Estimates of missing data are most commonly made on the basis of correlations with flow on adjacent drainages. Sometimes missing records are interpolated on a straight-line basis during periods of uniformly changing flow or by extension of hydrograph recession curves. In all cases, values for mean daily flows in the data listings that contain any estimated data are so indicated. We have no way of knowing the accuracy of the estimated data. However, a range of ± 15 percent would be a reasonable approximation. Estimated data are indicated with an "E."

The streamgauges at ZC-1, SC-5, and SC-6 were originally operated by the U.S. Geological Survey. Early streamflow records for these streams were originally published in two of the Survey's publications, "Surface Water Records of Idaho" (USGS 1960-1962) and "Surface Water Supply of the United States Part 13. Snake River Basin" (USGS 1963 and 1971). In these publications, ZC-1 is referred to as Tailholt Main, SC-5 is Cabin Creek, and SC-6 is Control Creek.

Silver Creek Study Area

SILVER CREEK STUDY AREA
WATERSHED: 1
WATERSHED AREA: 460 ACRES (186 HECTARES)

WATER YEAR 1965
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.152	0.216	0.375	0.564*	0.840*	0.685*	2.031*	2.066*	2.523*	0.297*	0.207	0.170
2	0.152	0.328	0.372	0.575*	0.826*	0.690*	2.251*	3.421*	2.290*	0.325*	0.221	0.165
3	0.152	0.233	0.337	0.593*	0.798*	0.696*	2.104*	4.943*	2.099*	0.322*	0.222	0.168
4	0.147	0.215	0.314	0.601*	0.692*	0.703*	1.822*	5.324*	1.925*	0.302*	0.208	0.167
5	0.141	0.202	0.299	0.541*	0.595*	0.710*	1.773*	4.494*	1.725*	0.287*	0.192	0.174
6	0.124	0.192	0.290	0.409*	0.572*	0.713*	1.889*	3.772*	1.538*	0.274*	0.187	0.183
7	0.125	0.187	0.285	0.323*	0.569*	0.713*	1.867*	3.415*	1.384*	0.266*	0.177	0.212
8	0.161	0.186	0.280	0.303*	0.568*	0.824*	1.917*	3.183*	1.244*	0.267*	0.168	0.230
9	0.142	0.186	0.279	0.301*	0.572*	1.261*	2.214*	3.325*	1.114*	0.306	0.168	0.206
10	0.139	0.208	0.280	0.305*	0.585*	1.731*	2.267*	3.727*	0.991*	0.293	0.164	0.184
11	0.137	0.208	0.265	0.308*	0.605*	1.871*	2.032*	4.342*	0.876*	0.260	0.167	0.180
12	0.135	0.212	0.260	0.310*	0.625*	1.737*	2.123*	5.077*	0.802*	0.255	0.294	0.174
13	0.131	0.203	0.262	0.313*	0.640*	1.573*	2.884*	5.654*	0.826*	0.238	0.246	0.180
14	0.131	0.233	0.262	0.283*	0.650*	1.558*	4.071*	6.089*	0.832*	0.225	0.203	0.187
15	0.261	0.230	0.262	0.218*	0.657*	1.586*	5.273*	5.974*	0.769*	0.215	0.191	0.233
16	0.192	0.200	0.266	0.186*	0.662*	1.645*	6.056*	5.576*	0.760*	0.209	0.186	0.217
17	0.166	0.200	0.275	0.192*	0.666*	1.671*	6.232*	5.296*	0.761*	0.199	0.175	0.206
18	0.162	0.194	0.281	0.206*	0.669*	1.662*	6.597*	4.710*	0.711*	0.193	0.170	0.211
19	0.157	0.195	0.284	0.217*	0.671*	1.673*	5.458*	4.227*	0.642*	0.193	0.275	0.210
20	0.152	0.193	0.288	0.221*	0.671*	1.692*	3.624*	4.230*	0.580*	0.208	0.281	0.203
21	0.148	0.191	0.456	0.226*	0.669*	1.717*	3.226*	4.217*	0.529*	0.198	0.307	0.203
22	0.148	0.196	11.078*	0.235*	0.666*	1.730*	3.226*	4.264*	0.490*	0.184	0.271	0.197
23	0.151	0.199	3.121	0.240*	0.665*	1.729*	2.834*	4.471*	0.478*	0.174	0.236	0.193
24	0.147	0.359	2.217	0.235*	0.666*	1.740*	2.538*	4.218*	0.399*	0.166	0.204	0.193
25	0.149	1.201	1.665	0.226*	0.669*	1.763*	2.709*	3.942*	0.374*	0.163	0.200	0.191
26	0.153	0.479	1.360	0.224*	0.671*	1.787*	2.752*	3.685*	0.428*	0.159	0.198	0.186
27	0.158	0.367	0.985	0.219*	0.673*	1.802*	2.560*	3.349*	0.413*	0.155	0.184	0.184
28	0.163	0.320	0.729*	0.194*	0.679*	1.808*	2.598*	3.231*	0.384*	0.167	0.180	0.192
29	0.161	0.299	0.689*	0.222*		1.812*	2.291*	3.157*	0.348*	0.209	0.180	0.190
30	0.166	0.345	0.635*	0.413*		1.814*	1.717*	3.033*	0.303*	0.219	0.178	0.191
31	0.167		0.592*	0.706*		1.822*		2.798*		0.209	0.173	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	4.770	8.178	29.339	10.109	18.494	44.917	90.939	129.212	28.540	7.134	6.411	5.778
TOTAL FLOW (cms days)	0.135	0.232	0.831	0.286	0.524	1.272	2.575	3.659	0.808	0.202	0.182	0.164
TOTAL DEPTH (in)	0.247	0.423	1.518	0.523	0.957	2.324	4.705	6.686	1.477	0.369	0.332	0.299
TOTAL DEPTH (cm)	0.627	1.075	3.856	1.329	2.431	5.903	11.952	16.982	3.751	0.938	0.843	0.759

ANNUAL SUMMARY:

Sum of Mean Daily Flow	383.822 cfs	10.870 cms
Total Depth	19.860 in	50.444 cm
Maximum Instantaneous Flow	16.403 cfs	0.465 cms on December 22 at 14.50 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 1
WATERSHED AREA: 460 ACRES (186 HECTARES)

WATER YEAR 1966
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.187	0.184	0.201*	0.480*	0.338*	0.245*	2.611*	0.916*	0.335	0.195	0.094	0.071
2	0.184	0.183	0.253*	0.461*	0.337*	0.235*	2.655*	1.019*	0.372	0.207	0.092	0.066
3	0.180	0.183	0.324*	0.443*	0.338*	0.226*	2.560*	1.162*	0.363	0.200	0.094	0.065
4	0.177	0.192	0.339*	0.424*	0.339*	0.216*	2.455*	1.177*	0.363	0.192	0.099	0.063
5	0.178	0.190	0.354*	0.406*	0.339*	0.208*	2.353*	1.136*	0.347	0.180	0.097	0.064
6	0.178	0.186	0.357*	0.390*	0.332*	0.206*	2.258*	1.045*	0.330	0.170	0.094	0.065
7	0.176	0.184	0.343*	0.374*	0.318*	0.205*	2.165*	0.973*	0.327	0.161	0.092	0.060
8	0.174	0.183	0.328*	0.358*	0.305*	0.209*	2.193*	0.919*	0.319	0.156	0.092	0.056
9	0.169	0.183	0.315*	0.344*	0.292*	0.216*	2.311*	1.336	0.356	0.153	0.089	0.057
10	0.166	0.188	0.303*	0.329*	0.280*	0.267*	2.442*	1.293	0.348	0.153	0.090	0.056
11	0.164	0.208	0.290*	0.315*	0.269*	0.323*	2.380*	1.088	0.324	0.144	0.085	0.057
12	0.172	0.210	0.278*	0.303*	0.258*	0.324*	2.100*	0.939	0.308	0.141	0.071	0.065
13	0.179	0.215	0.267*	0.290*	0.262*	0.358*	1.852*	0.836	0.293	0.141*	0.067	0.073
14	0.189	0.325	0.256*	0.289*	0.275*	0.397*	1.668*	0.810	0.281	0.133*	0.068	0.130
15	0.301	0.319	0.245*	0.297*	0.280*	0.393*	1.823*	0.761	0.271	0.136*	0.064	0.163
16	0.218	0.258	0.235*	0.294*	0.286*	0.405*	2.116*	0.711	0.268	0.151*	0.060	0.115
17	0.207	0.244	0.226*	0.282*	0.292*	0.429*	2.048*	0.641	0.268	0.202*	0.057	0.095
18	0.205	0.259	0.284*	0.271*	0.295*	0.435*	1.694*	0.593	0.254	0.233*	0.057	0.091
19	0.264	0.253	0.389*	0.281*	0.297*	0.425*	1.518*	0.571	0.246	0.193*	0.056	0.105
20	0.219	0.240	0.437*	0.299*	0.299*	0.407*	1.499*	0.557	0.245	0.157*	0.058	0.096
21	0.208	0.231	0.457*	0.305*	0.292*	0.390*	1.380*	0.533	0.246	0.153*	0.061	0.086
22	0.203	0.222	0.478*	0.313*	0.281*	0.374*	1.273*	0.538	0.248	0.150*	0.062	0.081
23	0.200	0.226	0.489*	0.321*	0.286*	0.359*	1.174*	0.519	0.264	0.147*	0.057	0.075
24	0.197	0.217	0.498*	0.324*	0.296*	0.345*	1.079*	0.496	0.270	0.143*	0.055	0.075
25	0.196	0.213	0.508*	0.326*	0.290*	0.369*	1.197*	0.460	0.248	0.140*	0.055	0.080
26	0.194	0.211	0.512*	0.331*	0.278*	0.523*	1.311*	0.417	0.234	0.108	0.065	0.094
27	0.193	0.221	0.517*	0.333*	0.267*	0.945*	1.208*	0.395	0.223	0.104	0.080	0.096
28	0.194	0.209*	0.527*	0.335*	0.256*	1.530*	1.112*	0.388	0.213	0.101	0.075	0.088
29	0.189	0.207*	0.533*	0.338*		1.696*	1.024*	0.375	0.207	0.099	0.074	0.084
30	0.188	0.206*	0.523*	0.339*		1.810*	0.962*	0.363	0.201	0.097	0.078	0.080
31	0.186		0.502*	0.339*		2.280*		0.374		0.095	0.074	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	6.036	6.551	11.565	10.533	8.276	16.750	54.422	23.340	8.622	4.734	2.311	2.454
TOTAL FLOW (cms days)	0.171	0.186	0.328	0.298	0.234	0.474	1.541	0.661	0.244	0.134	0.065	0.069
TOTAL DEPTH (in)	0.312	0.339	0.598	0.545	0.428	0.867	2.816	1.208	0.446	0.245	0.120	0.127
TOTAL DEPTH (cm)	0.793	0.861	1.520	1.384	1.088	2.201	7.153	3.067	1.133	0.622	0.304	0.323

ANNUAL SUMMARY:
Sum of Mean Daily Flow 155.594 cfs = 4.406 cms
Total Depth 8.051 in = 20.449 cm
Maximum Instantaneous Flow 2.698 cfs = 0.076 cms on April 1 at 24.00 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 1
WATERSHED AREA. 460 ACRES (186 HECTARES)

WATER YEAR 1967
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.[illegible]	0.113	0.442	0.[illegible]	0.505	0.446	0.697*	0.[illegible]*	1.199	0.372	0.1[illegible]	0.124
2	0.1[illegible]	0.114	0.498	0.275	0.452	0.411	0.708*	1.[illegible]*	1.867	0.356	0.132	0.123
3	0.112	0.114	0.437	0.[illegible]	0.420	0.380	0.867*	1.276*	1.647	0.350	0.127	0.123
4	0.[illegible]	0.115	0.378	0.255	0.398	0.361*	1.146*	1.779*	1.490	0.335	0.[illegible]	0.120
5	0.[illegible]	0.119	0.363	0.[illegible]	0.[illegible]	0.350	1.217*	1.546*	1.416	0.321	0.119	0.125
6	0.[illegible]	0.157	0.324	0.[illegible]	0.368	0.381	1.134*	1.362*	1.403	0.311	0.113	0.[illegible]
7	0.[illegible]	0.154	0.307	0.[illegible]	0.[illegible]	0.399	1.272*	[illegible]	1.301	0.300	0.[illegible]	0.127
8	0.[illegible]	0.141	0.302	0.[illegible]	0.354	0.406	1.602*	[illegible]	1.103	0.293	0.[illegible]	0.134
9	0.[illegible]	0.134	0.318	0.[illegible]	0.349	0.391	1.867*	[illegible]	1.[illegible]	0.284	0.[illegible]	0.[illegible]
10	0.[illegible]	0.138	0.321	0.[illegible]	0.337	0.[illegible]	1.985*	6.670*	1.072	0.261*	0.[illegible]	0.130
11	0.094	0.138	0.270	0.[illegible]	0.[illegible]	0.367	1.967*	[illegible]	[illegible]	0.267*	0.105	0.242
12	0.[illegible]	0.167	0.[illegible]	0.[illegible]	0.310	0.[illegible]	1.089*	[illegible]	1.036	0.258*	0.100	0.105
13	0.[illegible]	0.[illegible]	0.265	0.216	0.312	0.[illegible]	[illegible]	[illegible]	0.[illegible]	0.245*	0.101	0.[illegible]
14	0.[illegible]	0.204	0.[illegible]	0.[illegible]	0.304	0.[illegible]	1.012*	[illegible]	0.[illegible]	0.[illegible]*	0.091*	0.137
15	0.[illegible]	0.[illegible]	0.263	0.[illegible]	0.292	0.[illegible]	1.793*	3.520*	0.766	0.226*	0.097*	0.132
16	0.[illegible]	0.330	0.218	0.245	0.287	0.[illegible]	1.[illegible]*	[illegible]	0.723	0.218*	0.[illegible]	0.130
17	0.[illegible]	0.408	0.[illegible]	0.[illegible]	0.284	0.[illegible]	1.464*	[illegible]	0.702	0.[illegible]*	0.[illegible]	0.[illegible]
18	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.280	0.[illegible]	1.179*	[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]
19	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.270*	0.[illegible]*	1.701*	[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]
20	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]*	0.[illegible]*	1.[illegible]*	[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]
21	0.[illegible]	0.[illegible]	0.[illegible]*	0.[illegible]	0.[illegible]*	0.[illegible]*	1.071*	0.230	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]
22	0.[illegible]	0.[illegible]	0.[illegible]*	0.[illegible]	0.[illegible]*	0.[illegible]*	[illegible]*	[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]
23	0.[illegible]	0.[illegible]	0.[illegible]*	0.[illegible]	0.[illegible]	0.[illegible]*	0.[illegible]*	[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]
24	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]*	1.[illegible]*	[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]
25	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]*	1.[illegible]*	[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]
26	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]*	[illegible]*	[illegible]	0.450	0.[illegible]	0.[illegible]	0.[illegible]
27	0.127	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]*	1.159*	[illegible]	0.451	0.[illegible]	0.[illegible]	0.[illegible]
28	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.440	0.[illegible]*	1.[illegible]*	[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]
29	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]		0.[illegible]*	1.[illegible]*	[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]
30	0.117	0.[illegible]	0.[illegible]	0.[illegible]		0.[illegible]*	1.046*	[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]
31	0.[illegible]		0.[illegible]	0.616		0.[illegible]*		[illegible]		0.[illegible]	0.[illegible]	

MONTHLY SUMMARY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	3.[illegible]	7.[illegible]	9.[illegible]	[illegible]	9.466	17.707	48.[illegible]	128.185	29.598	[illegible]	[illegible]	[illegible]
TOTAL FLOW (cms days)	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	1.[illegible]	3.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]	0.[illegible]
TOTAL DEPTH (in)	0.[illegible]	0.[illegible]	0.[illegible]	0.450	0.480	0.916	2.05[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TOTAL DEPTH (cm)	0.[illegible]	1.0[illegible]	1.3[illegible]	1.[illegible]	1.2[illegible]	2.[illegible]	5.312	16.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

ANNUAL SUMMARY
Sum of Mean Daily Flow [illegible] cfs ([illegible] cms)
Total Depth [illegible] in (39.350 cm)
Maximum Instantaneous Flow 7.[illegible] cfs (0.2[illegible] cms) on May 21 at 2[illegible] hours

* Indicates some data were estimated during this day

SILVER CREEK STUDY AREA
WATERSHED: 1
WATERSHED AREA: 460 ACRES (186 HECTARES)

WATER YEAR 1968
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.299	0.243	0.200	0.308*	0.245*	2.007*	2.151	2.030	0.476	0.252	0.099	0.131
2	0.302	0.229	0.198	0.286*	0.235*	2.133	2.416	1.852	0.455	0.238	0.098	0.131
3	0.705	0.218	0.200	0.267*	0.226*	2.193	2.328	1.747	0.454	0.223	0.097	0.131
4	0.222	0.201	0.203	0.258*	0.230*	2.365	2.214	1.702	0.433	0.209	0.097	0.137
5	0.210	0.196	0.207	0.246*	0.237*	2.505	2.351	1.618	0.415	0.200	0.096	0.142
6	0.209	0.189	0.200	0.239*	0.259*	2.290	2.117	1.372	0.475	0.191	0.093	0.141
7	0.186	0.185	0.200	0.239*	0.322*	1.975	1.890	1.239	0.469	0.181	0.091	0.141
8	0.173	0.182	0.195	0.240*	0.376*	1.675	1.716	1.128	0.428	0.175	0.088	0.140
9	0.164	0.206	0.192*	0.238*	0.409*	1.468	1.712	1.109	0.435	0.180	0.087	0.139
10	0.156	0.236	0.201*	0.234*	0.472*	1.312	2.136	1.160	0.433	0.148	0.165	0.138
11	0.153	0.377	0.196*	0.232*	0.532*	1.197	2.769	1.161	0.384*	0.142	0.147	0.136
12	0.170	0.443	0.190*	0.230*	0.567*	1.101	2.601	1.243	0.360*	0.147	0.131	0.135
13	0.163	0.398	0.178*	0.223*	0.637*	1.129	2.197	1.351	0.343	0.157	0.138	0.135
14	0.161	0.351	0.169*	0.213*	0.663*	1.041	1.968	1.221	0.333	0.149	0.308	0.138
15	0.158	0.324	0.166*	0.212*	0.600*	0.980	1.810	1.060	0.321	0.146	0.353	0.192
16	0.155	0.288	0.163*	0.224*	0.547*	0.980	1.636	0.918	0.309	0.144	0.197	0.175
17	0.149	0.270	0.159*	0.230*	0.469*	0.963	1.492	0.831	0.298	0.144	0.190	0.157
18	0.147	0.269	0.155*	0.221*	0.397*	0.889	1.419	0.771	0.289	0.141	0.266	0.159
19	0.144	0.264	0.153*	0.216*	1.633*	0.845	1.353	0.726	0.287	0.137	0.280	0.170
20	0.144	0.249	0.150*	0.213*	4.798*	0.866	1.227	0.845	0.300	0.134	0.308	0.185
21	0.157	0.240	0.143*	0.209*	2.695	0.945	1.149	0.765	0.283	0.130	0.566	0.232
22	0.182	0.231	0.139*	0.211*	1.863	1.048	1.104	0.699	0.301	0.126	0.358	0.250
23	0.189	0.225	0.147*	0.216*	1.978	1.270	1.093	0.655	0.311	0.123	0.295	0.232
24	0.179	0.223	0.158*	0.245*	2.151	1.435	1.147	0.613	0.280	0.120	0.239	0.212
25	0.170	0.220	0.193*	0.294*	1.893	1.437	1.168	0.765	0.261	0.118	0.199	0.188
26	0.159	0.213	0.304*	0.316*	1.686	1.353	1.145	0.789	0.260	0.114	0.179	0.174
27	0.215	0.207	0.381*	0.305*	1.548*	1.260	1.142	0.666	0.252	0.109	0.168	0.164
28	1.089	0.205	0.360*	0.287*	1.604	1.272	1.295	0.609	0.249	0.105	0.161	0.162
29	0.424	0.203	0.336*	0.268*	1.802*	1.599	1.626	0.566	0.260	0.103	0.150	0.158
30	0.314	0.201	0.330*	0.259*		1.936	1.997	0.535	0.266	0.102	0.136	0.156
31	0.268		0.323*	0.249*		1.999		0.504		0.101	0.131	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	7.516	7.486	6.486	7.626	31.075	45.468	52.366	32.248	10.418	4.689	5.912	4.881
TOTAL FLOW (cms days)	0.213	0.212	0.184	0.216	0.880	1.288	1.483	0.913	0.295	0.133	0.167	0.138
TOTAL DEPTH (in)	0.389	0.387	0.336	0.395	1.608	2.353	2.710	1.669	0.539	0.243	0.306	0.253
TOTAL DEPTH (cm)	0.988	0.984	0.852	1.002	4.084	5.976	6.882	4.238	1.369	0.616	0.777	0.642

ANNUAL SUMMARY:
Sum of Mean Daily Flow 216.172 cfs = 6.122 cms
Total Depth 11.185 in = 28.411 cm
Maximum Instantaneous Flow 6.755 cfs = 0.191 cms on February 20 at 1.50 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 1
WATERSHED AREA: 460 ACRES (186 HECTARES)

WATER YEAR 1969
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.155	0.190*	0.350	0.306*	0.556	0.413*	4.322	3.513	0.935	0.391*	0.168	0.136
2	0.154	0.181*	0.317	0.318*	0.541	0.414	4.968*	3.351	0.881	0.374	0.165	0.133
3	0.153	0.174*	0.308	0.319	0.528	0.427	5.107	3.367	0.833	0.374	0.161	0.130
4	0.153	0.167*	0.303	0.320	0.521	0.434	4.922	3.944	0.799*	0.374	0.155	0.127
5	0.152	0.187	0.302	0.383*	0.513	0.456	6.140*	4.762	0.762*	0.364	0.150	0.124
6	0.151	0.212	0.299	0.529	0.504	0.464	7.153*	5.377	0.725*	0.375	0.160	0.121
7	0.151	0.212	0.295	0.555*	0.497	0.458	5.625	5.835	0.696*	0.358	0.168	0.118
8	0.151	0.212	0.291	0.512*	0.486	0.447	4.481	5.958	0.668*	0.331	0.167	0.116
9	0.151	0.347	0.288	0.479	0.476	0.439	5.169*	5.728	0.640*	0.309	0.164	0.113
10	0.151	0.401	0.292	0.459*	0.472	0.431	5.847*	5.358	0.581	0.293	0.162	0.110
11	0.154	0.410	0.323	0.447	0.464	0.427	5.722*	4.887	0.540	0.280	0.165	0.109
12	0.212	1.054	0.307	0.437	0.456	0.425	6.103*	4.370	0.512	0.276	0.170	0.107
13	0.266	0.727	0.313	0.492*	0.450	0.436	6.448*	4.066	0.483	0.269	0.167	0.104
14	0.266	0.510	0.307	0.509	0.444	0.458	6.029	4.661	0.449	0.259	0.165	0.102
15	0.272	0.425	0.301	0.493*	0.440	0.454	5.516	3.833	0.441	0.250	0.169	0.100
16	0.271	0.366	0.304	0.477*	0.436	0.540	5.665*	3.193	0.415	0.242	0.168	0.097
17	0.268	0.332	0.294	0.467	0.430	0.550	5.927*	2.822	0.385	0.233	0.165	0.095
18	0.248	0.336	0.292	0.459	0.426	0.571	6.860*	2.661	0.373	0.227	0.167	0.093
19	0.233	0.378	0.290	0.454	0.423	0.551	6.049*	2.529	0.411	0.218	0.169	0.122
20	0.227	0.383	0.296	0.462*	0.422	0.535	5.394	2.542	0.450	0.211	0.169	0.214
21	0.239	0.383	0.302	1.086	0.423	0.585	7.089*	2.209	0.421	0.205	0.168	0.161
22	0.238	0.787	0.302*	0.953*	0.424	0.698	10.652*	1.998	0.390	0.198	0.166	0.140
23	0.232	0.822	0.307*	0.790*	0.424	0.721	10.849	1.837	0.469	0.193	0.165	0.146
24	0.225	0.599	0.317	0.729	0.423	0.700	8.927	1.684	1.026	0.195	0.164	0.150
25	0.213	0.500	0.317	0.698	0.422	0.811	6.036	1.521	0.676	0.193	0.161	0.134
26	0.203	0.434	0.302	0.686	0.420	1.191	4.899	1.411	0.583	0.188	0.156	0.132
27	0.198	0.403	0.293	0.655	0.419	1.417	4.587	1.318	0.509	0.184	0.152	0.130
28	0.192	0.377	0.313	0.629	0.417	1.537*	4.585	1.191	0.494	0.180	0.149	0.128
29	0.186	0.406	0.313	0.603		2.182	4.872	1.101	0.478	0.180	0.145	0.125
30	0.195	0.329	0.308	0.586		3.254	3.993	1.095	0.435	0.176	0.142	0.129
31	0.195*		0.305	0.572		4.229		0.991		0.172	0.139	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	6.251	12.243	9.448	16.866	12.858	26.655	179.936	99.110	17.460	8.072	4.999	3.744
TOTAL FLOW (cms days)	0.177	0.347	0.268	0.478	0.364	0.755	5.096	2.807	0.494	0.229	0.142	0.106
TOTAL DEPTH (in)	0.323	0.634	0.489	0.873	0.665	1.379	9.310	5.128	0.903	0.418	0.259	0.194
TOTAL DEPTH (cm)	0.822	1.609	1.242	2.217	1.690	3.503	23.648	13.026	2.295	1.061	0.657	0.492

ANNUAL SUMMARY:
Sum of Mean Daily Flow 397.642 cfs = 11.261 cms
Total Depth 20.575 in = 52.261 cm
Maximum Instantaneous Flow 13.502 cfs = 0.382 cms on April 23 at 19.50 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 5
WATERSHED AREA 400 ACRES (160 HECTARES)

WATER YEAR 1970
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.163	[illegible]	0.203	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.107
2	[illegible]	0.179	0.210	[illegible]	[illegible]	0.784	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.106
3	0.179	0.178	0.209	0.248	0.364	0.714	0.804	[illegible]	2.093	[illegible]	[illegible]	0.108
4	0.169	0.177	0.209	0.253	0.346	0.665	0.861	7.490*	1.912	0.674	0.223	0.156
5	0.163	0.165	0.209	0.258	0.334	0.616	1.342	10.231	1.784	[illegible]	0.150	0.160
6	0.162	0.227	0.209	0.263	0.330	0.590	[illegible]	10.870	1.661	[illegible]	[illegible]	0.144
7	0.157	0.239	0.209	0.269	0.344	0.583	3.087	[illegible]	1.542	[illegible]	[illegible]	[illegible]
8	0.198	0.217	0.209	0.271	0.388	0.696	2.606	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	0.215	0.206	0.209	0.272	0.502	0.697	2.598	[illegible]	1.342	0.450	[illegible]	0.178
10	0.192	0.201	0.209	0.275	0.613	0.678	4.191	6.019	1.343	0.533	[illegible]	0.152
11	0.179	0.199	0.208	0.275	0.642	0.672	3.679	4.792	1.222	0.478	0.189	0.151
12	0.175	0.194	0.194	0.275	0.876	0.641	2.740	4.027	1.126	0.433	0.183	0.149
13	0.175	0.190	0.195*	0.275	0.944	0.612	2.357	3.341	1.074	0.407	0.176	0.155
14	0.175	0.188	0.197*	0.275	0.742	0.654	2.002	3.033	1.408	0.393	0.179	0.160
15	0.175	0.186	0.198	0.274	0.648	0.838	1.735	3.749	1.751	0.376	0.174	0.162
16	0.175	0.186	0.197	0.272	0.605	0.860	1.594	6.346*	1.606	0.365	0.169	0.157
17	0.175	0.183	0.196	0.271	0.602	0.797	1.715	9.697	1.415	0.364	0.165	0.149
18	0.175	0.204	0.194	0.270	0.567	0.740	1.895	10.392	1.262	0.348	0.163	0.135
19	0.174	0.194	0.195	0.264*	0.534	0.699	1.861	8.558	1.148	0.330	0.156	0.218
20	0.173	0.190	0.205	0.253*	0.514	0.690	1.695	7.414	1.071	0.318	0.151	0.228
21	0.173	0.187	0.655	0.273*	0.518	0.719	1.565	6.841	1.015*	0.319	0.146	0.214
22	0.171	0.196	0.462	0.409*	0.576	0.787	1.459	6.193	0.960*	0.313	0.137	0.192
23	0.169	0.235	0.279	1.214	0.644	0.830	1.349	6.679*	0.904*	0.304	0.139	0.184
24	0.167	0.196	0.232*	2.413	0.700	0.892	1.275	5.720	0.854*	0.298	0.129	0.168
25	0.167	0.193	0.212*	1.887*	0.768	0.900	1.210	5.265	0.808*	0.297	0.117	0.162
26	0.167	0.209	0.210	1.612*	0.828	0.940	1.138	4.857	0.756	0.290	0.115	0.155
27	0.167	0.193*	0.208	0.897*	0.886	1.014	1.062	4.350	0.913	0.289	0.113	0.148
28	0.198	0.195*	0.210	0.660*	0.893	1.129	1.008	3.639	1.008	0.306	0.114	0.144
29	0.189	0.197*	0.220	0.634*		1.008	0.965	3.140	1.771	0.290	0.114	0.138
30	0.186	0.200	0.225	0.608*		0.880	0.946	2.753	1.337	0.274	0.107	0.133
31	0.186		0.229	0.583*		0.863		2.451		0.264	0.109	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	5.517	5.904	7.210	16.478	16.668	24.011	53.197	178.570	41.031	13.425	5.304	[illegible]
TOTAL FLOW (cms days)	0.156	0.167	0.204	0.467	0.472	0.680	1.507	5.057	1.162	0.380	0.150	0.139
TOTAL DEPTH (in)	0.285	0.305	0.373	0.853	0.862	1.242	2.753	9.240	2.123	0.695	0.274	0.253
TOTAL DEPTH (cm)	0.725	0.776	0.948	2.166	2.191	3.156	6.992	23.469	5.392	1.764	0.697	0.643

ANNUAL SUMMARY:
Sum of Mean Daily Flow 372.210 cfs - 10.541 cms
Total Depth 19.259 in - 48.918 cm
Maximum Instantaneous Flow 13.474 cfs - 0.382 cms on May 5 at 19 25 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 1
WATERSHED AREA: 460 ACRES (186 HECTARES)

WATER YEAR 1971
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.130	0.314	0.639	0.515	1.511	0.742	1.164	11.264	2.360	0.894	0.235	0.157
2	0.132	0.316	0.591	0.515	1.520	0.740	1.260	13.947	2.137	0.829	0.259	0.174
3	0.132	0.297	0.547*	0.516	1.303	0.740	1.490	14.480	1.923	0.754	0.242	0.178
4	0.130	0.278	0.526*	0.522	1.213	0.740	1.792	14.535	1.823	0.695	0.219	0.168
5	0.135	0.344	0.499	0.528	1.117	0.740	2.366	15.565	1.597	0.648	0.212	0.162
6	0.144	0.497	0.560	0.538	1.061	0.742	3.113	14.289	1.445	0.621	0.217	0.164
7	0.150	0.544	0.640	0.548	1.004	0.743	4.432	13.699	1.322	0.587	0.204	0.199
8	0.150	0.444*	0.645	0.556	0.957	0.743	3.848	12.855	1.321*	0.559	0.192	0.165
9	0.180	0.779	0.600	0.559	0.928	0.743	3.645	13.193	1.311*	0.546	0.181	0.155
10	0.210	0.809	0.554	0.562	0.964	0.687	3.689	12.116	1.225*	0.516	0.174	0.149
11	0.180	0.564	0.541	0.564	0.960	0.634	3.137	11.546	1.252	0.499	0.171	0.148
12	0.168	0.476	0.521*	0.564	0.961	0.633	2.783	11.103	1.287	0.472	0.169	0.147
13	0.159	0.416	0.516*	0.564	1.014	0.619	2.940	10.938	1.207	0.457	0.165	0.145
14	0.157	0.382	0.513*	0.572	1.060	0.602	4.237	8.461	1.117	0.449	0.169	0.142
15	0.154	0.361	0.507*	0.579	1.073	0.592	5.268	7.190	1.021	0.433	0.163	0.147
16	0.152	0.345	0.493	0.579	1.055	0.583	4.639	6.529	0.966	0.411	0.163	0.151
17	0.149	0.327	0.473	0.578	1.015	0.581	4.309	5.100	0.892	0.395	0.164	0.152
18	0.150	0.330	0.463	0.576	0.978	0.583	4.101	4.345	0.865	0.380	0.162	0.157
19	0.179	0.322	0.459	0.573	0.944	0.589	5.057*	3.911	0.838	0.411	0.160	0.158
20	0.183	0.317	0.456	0.568	0.908	0.625	6.728*	3.515	0.763	0.406	0.156	0.155
21	0.201	0.296*	0.457	0.565	0.886	0.659	7.932	3.201	0.712	0.370	0.156	0.154
22	0.212	0.290*	0.459	0.562	0.879	0.668	7.265	3.253	0.679	0.355	0.154	0.154
23	0.215	0.416	0.463	0.559	0.868	0.687*	6.004	3.422	0.661	0.339	0.158	0.153
24	0.217	6.387	0.469	0.556	0.876	0.814	5.208	3.546	0.633	0.325	0.157	0.150
25	0.209	3.771	0.473	0.553	0.854	0.824	5.243	3.556	0.771	0.312	0.156	0.152
26	0.210	1.654	0.482	0.548	0.822	0.957	5.784	3.637	1.701	0.301	0.155	0.174
27	0.206*	1.027	0.498	0.638	0.797	1.051	5.899	3.567	1.665	0.291	0.153	0.184
28	0.230*	0.826	0.510	0.794	0.763	0.974	6.495*	3.433	1.584	0.277	0.151	0.182
29	0.275	0.724	0.512	0.841		0.978	7.461*	3.102	1.258	0.265	0.152	0.214
30	0.303	0.703	0.512	0.847		1.179	8.638	2.839	1.036	0.258	0.160	0.212
31	0.301		0.513	1.110		1.217		2.444		0.242	0.157	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	5.706	24.555	16.094	18.651	28.290	23.407	135.927	244.579	37.374	14.297	5.484	4.903
TOTAL FLOW (cms days)	0.162	0.695	0.456	0.528	0.801	0.663	3.849	6.926	1.058	0.405	0.155	0.139
TOTAL DEPTH (in)	0.295	1.271	0.833	0.965	1.464	1.211	7.033	12.655	1.934	0.740	0.284	0.254
TOTAL DEPTH (cm)	0.750	3.227	2.115	2.451	3.718	3.076	17.864	32.144	4.912	1.879	0.721	0.644

ANNUAL SUMMARY:
Sum of Mean Daily Flow 559.268 cfs = 15.838 cms
Total Depth 28.938 in = 73.503 cm
Maximum Instantaneous Flow 17.437 cfs = 0.494 cms on May 4 at 23.75 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 1
WATERSHED AREA: 460 ACRES (186 HECTARES)

WATER YEAR 1972
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.211	0.209	0.214*	0.225*	0.245	0.986	1.571	4.692	2.108	0.499	0.189	0.143
2	0.196	0.199	0.236*	0.223*	0.241	0.781	2.086	5.279	1.779	0.477	0.193	0.140
3	0.182	0.202*	0.242*	0.229*	0.244	0.933	2.645	6.954	1.544	0.462	0.179	0.142
4	0.174	0.207*	0.225*	0.234*	0.246	0.759	2.691	9.560	1.347	0.446	0.175	0.142
5	0.170	0.208*	0.225*	0.234*	0.246	0.658	3.475	10.032	1.185	0.422	0.165	0.185
6	0.168	0.209*	0.231*	0.234*	0.253	0.612	4.819	10.014	1.108	0.406	0.160	0.209
7	0.164	0.214*	0.233*	0.234*	0.248	0.621	4.426	8.998	1.203*	0.404	0.155	0.162
8	0.161	0.215*	0.233*	0.233*	0.246	0.637	3.558	8.721	1.500*	0.385	0.155	0.160
9	0.159	0.214*	0.237*	0.231*	0.246	1.052	3.358	6.827	2.523	0.390	0.152	0.159
10	0.159	0.216*	0.239*	0.229*	0.246	2.283	3.200	6.167	2.796	0.376	0.153	0.164
11	0.160	0.231*	0.239*	0.230*	0.246	3.082	2.875	6.230	2.204	0.360	0.152	0.178
12	0.155	0.254*	0.239*	0.231*	0.244	2.795	2.674	6.512	1.719	0.340	0.149	0.190
13	0.156	0.253*	0.239*	0.229*	0.241	3.446	2.396	7.379*	1.422	0.325	0.149	0.185
14	0.160	0.235*	0.239*	0.227*	0.241	3.610	2.131	8.361*	1.221	0.317	0.177	0.175
15	0.165	0.225*	0.239*	0.227*	0.241	3.466	1.961	9.164*	1.058	0.309	0.225	0.166
16	0.166	0.217*	0.238*	0.227*	0.241	4.238	1.996	9.076*	0.986	0.301	0.201	0.161
17	0.162	0.213*	0.237*	0.227*	0.246	5.245*	1.855	8.352*	0.910	0.288	0.173	0.153
18	0.165	0.209*	0.234*	0.227*	0.262	5.345	1.692	6.679	0.846	0.279	0.166	0.151
19	0.177	0.206*	0.231*	0.229*	0.294	4.200	1.773	5.406	0.796	0.282	0.159	0.174
20	0.255	0.207*	0.229*	0.233*	0.318	3.363	2.159	5.100	0.731	0.291	0.159	0.169
21	0.228	0.211*	0.227*	0.253*	0.359	3.370	2.421	4.425	0.710	0.294	0.161	0.156
22	0.213	0.212*	0.235*	0.264*	0.364	4.527*	2.563	3.993	0.701	0.280	0.150	0.158
23	0.201	0.209*	0.247*	0.248*	0.351	5.090	3.378	3.586	0.665	0.259	0.150	0.158
24	0.201	0.209*	0.244*	0.234*	0.330	3.574	3.993	3.338	0.647	0.246	0.151	0.168
25	0.200	0.212*	0.235*	0.229*	0.314	2.810	3.610	3.070	0.745	0.238	0.146	0.177
26	0.206	0.214*	0.234*	0.226*	0.304	2.231	3.457	2.871	0.640	0.230	0.142	0.172
27	0.209	0.221*	0.233*	0.225*	0.495	1.795	4.749*	2.821	0.582	0.223	0.139	0.194
28	0.200*	0.222*	0.231*	0.224*	1.904	1.506	6.792*	2.802	0.528	0.213	0.174	0.185
29	0.228*	0.218*	0.230*	0.222*	1.719	1.318	7.287*	2.766	0.501	0.204	0.179	0.179
30	0.213	0.216*	0.229*	0.246		1.182	4.865	2.643	0.508	0.191	0.156	0.178
31	0.209		0.227*	0.246		1.329		2.430		0.195	0.148	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	5.770	6.489	7.250	7.211	11.174	76.845	96.457	184.246	35.212	9.929	5.082	5.033
TOTAL FLOW (cms days)	0.163	0.184	0.205	0.204	0.316	2.176	2.732	5.218	0.997	0.281	0.144	0.143
TOTAL DEPTH (in)	0.299	0.336	0.375	0.373	0.578	3.976	4.991	9.533	1.822	0.514	0.263	0.260
TOTAL DEPTH (cm)	0.758	0.853	0.953	0.948	1.469	10.099	12.677	24.215	4.628	1.305	0.668	0.661

ANNUAL SUMMARY:
Sum of Mean Daily Flow 450.698 cfs = 12.764 cms
Total Depth 23.320 in = 59.234 cm
Maximum Instantaneous Flow 13.308 cfs = 0.377 cms on May 4 at 17.50 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 1
WATERSHED AREA: 460 ACRES (186 HECTARES)

WATER YEAR 1973
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.175	0.181	0.196	0.230	0.275	0.544*	0.750	1.894	0.433	0.195	0.104*	0.116*
2	0.171	0.191	0.193	0.225	0.268	0.568*	0.711	1.799	0.417	0.193	0.106*	0.112*
3	0.169	0.195	0.195	0.221	0.265	0.542*	0.775	1.925	0.407	0.189	0.113*	0.105*
4	0.170	0.252	0.175	0.220	0.256	0.506*	1.166	2.227	0.383	0.181	0.117*	0.100*
5	0.168	0.263	0.198*	0.216	0.254	0.488*	1.537	2.118	0.365	0.179	0.112*	0.096*
6	0.166	0.218	0.223*	0.212	0.254	0.482*	1.585	2.049	0.346	0.178	0.109*	0.106
7	0.165	0.212	0.223*	0.208	0.249	0.478*	1.371	1.927	0.328	0.177	0.109*	0.274
8	0.162	0.218	0.223*	0.206	0.245	0.475*	1.325	2.041	0.312	0.176	0.105*	0.133
9	0.166	0.210	0.224*	0.207	0.244	0.481*	1.298	1.767	0.301	0.174	0.102*	0.117
10	0.257	0.206	0.226*	0.207	0.244	0.484*	1.395	1.503	0.287	0.172	0.102*	0.116*
11	0.266	0.205	0.229*	0.195	0.244	0.459*	1.856	1.285	0.274	0.158*	0.103*	0.113*
12	0.196	0.202	0.230*	0.224*	0.242	0.437*	2.514	1.187	0.268	0.153*	0.100*	0.110*
13	0.175	0.200	0.230*	0.374*	0.240	0.434*	3.646	1.167	0.270	0.152*	0.096*	0.109*
14	0.173	0.198	0.230*	0.541*	0.237	0.422	3.421	1.157	0.364	0.148*	0.096*	0.117*
15	0.188	0.197	0.229*	0.522	0.235	0.408	2.807	1.106	0.340	0.143*	0.095*	0.125*
16	0.181	0.198	0.229*	0.721	0.237	0.443	2.406	1.027	0.314	0.138*	0.094*	0.125*
17	0.174	0.217	0.231*	0.665	0.237	0.494	2.197	0.946	0.396	0.132*	0.093*	0.124*
18	0.169	0.213	0.233*	0.522	0.237	0.476	1.896	0.879	0.348	0.116	0.094*	0.126
19	0.169	0.206	0.237*	0.446	0.235	0.466	1.646	0.810	0.314	0.135	0.096*	0.166
20	0.167	0.194	0.251	0.401	0.234	0.470	1.476	0.757*	0.286	0.141	0.096*	0.326
21	0.167	0.196	0.479	0.372	0.235	0.478	1.473	0.695*	0.268	0.137	0.099*	0.172
22	0.167	0.221	2.807*	0.361	0.237	0.480	1.673	0.639*	0.247	0.126	0.102*	0.149
23	0.168	0.194	0.491	0.360	0.238	0.508	2.065	0.587	0.246	0.116	0.101*	0.168
24	0.171	0.193	0.380	0.350	0.242	0.685	2.379	0.635	0.244	0.115	0.099*	0.412
25	0.173	0.193	0.323	0.334	0.246	1.013	2.510	0.782	0.236	0.107	0.107*	0.333
26	0.171	0.248	0.285	0.323	0.248	1.109	2.688	0.633	0.226	0.108	0.109*	0.192
27	0.173	0.202	0.266	0.319	0.245	0.933	3.040	0.561	0.220	0.107	0.103*	0.161
28	0.175	0.201*	0.249	0.317	0.371*	0.815	2.819	0.515	0.212	0.107	0.100*	0.155
29	0.175	0.195	0.236	0.307		0.792	2.338	0.482	0.206	0.108	0.097*	0.149
30	0.174	0.196	0.234	0.291		0.817	2.044	0.456	0.198	0.108	0.096*	0.148
31	0.175		0.231	0.283		0.802		0.454		0.107	0.104*	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	5.518	6.217	10.383	10.381	6.994	17.989	58.807	36.007	9.054	4.475	3.158	4.756
TOTAL FLOW (cms days)	0.156	0.176	0.294	0.294	0.198	0.509	1.665	1.020	0.256	0.127	0.089	0.135
TOTAL DEPTH (in)	0.286	0.322	0.537	0.537	0.362	0.931	3.043	1.863	0.468	0.232	0.163	0.246
TOTAL DEPTH (cm)	0.725	0.817	1.365	1.364	0.919	2.364	7.729	4.732	1.190	0.588	0.415	0.625

ANNUAL SUMMARY:

Sum of Mean Daily Flow 173.738 cfs = 4.920 cms
Total Depth 8.990 in = 22.834 cm
Maximum Instantaneous Flow 9.367 cfs = 0.265 cms on December 22 at 11.08 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 1
WATERSHED AREA: 460 ACRES (186 HECTARES)

WATER YEAR 1974
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.149	0.518	0.509	0.420*	0.671	0.649	2.662	9.768	2.955	0.432	0.159	0.118
2	0.149	0.251	0.495	0.416*	0.647	0.601	2.322	9.705	2.863	0.429	0.167	0.120
3	0.149	0.192	0.467	0.424*	0.628	0.565	2.060	9.710	2.770	0.408	0.167	0.119
4	0.146	0.173	0.450	0.434*	0.627	0.552	1.841	10.480	2.745	0.392	0.162	0.115
5	0.140	0.167	0.432	0.439*	0.603	0.555	1.754	12.247	2.770	0.384	0.156	0.115
6	0.139	0.372	0.424	0.443*	0.587	0.538	1.942	12.147	2.385	0.376	0.208	0.113
7	0.257	0.394	0.452	0.446*	0.572	0.530	1.852	12.306	2.108	0.373	0.242	0.108
8	0.203	0.374	0.454	0.447*	0.572	0.523*	2.017	12.729	1.864	0.385	0.195	0.104
9	0.181	0.813*	0.439	0.449*	0.564	0.510	2.331	11.329	1.688	0.479	0.180	0.105
10	0.172	2.977	0.437	0.453*	0.559	0.572	2.207	8.780	1.559	0.505	0.167	0.112
11	0.165	3.799	0.438	0.456*	0.561	0.598	2.253	7.177	1.488	0.513	0.161	0.114
12	0.166	4.943*	0.426	0.453*	0.562	0.682	2.356	6.528	1.408	0.427	0.157	0.122
13	0.162	2.470	0.421	0.484*	0.551	0.716*	2.290	5.571	1.324	0.373	0.152	0.121
14	0.157	1.532	0.412	0.814*	0.541	0.713*	2.783	4.826	1.216	0.340	0.153	0.113
15	0.153	1.154	0.405	1.791*	0.531	0.683	3.620	4.258	1.132	0.338	0.144	0.108
16	0.149	0.977	0.490	3.396*	0.529	0.851	4.776	3.804	1.027	0.312	0.132	0.104
17	0.145	0.831	0.620	3.613*	0.519	2.643	6.224	3.609	0.946	0.291	0.126	0.100
18	0.143	0.732	0.570	2.553*	0.519	2.476	8.245	3.395	0.879	0.278	0.121	0.098
19	0.139	0.646	0.539	1.965*	0.509	2.187	9.198	3.273	0.788	0.269	0.136	0.096
20	0.144	0.598	0.523	1.615*	0.495	1.841	8.509	3.310	0.839	0.255	0.216	0.102
21	0.151	0.558	0.521	1.459*	0.494	1.656	8.108	3.297*	0.753	0.242	0.168	0.098
22	0.148	0.522	0.496	1.307*	0.484*	1.533	8.594	3.442*	0.696	0.226	0.157	0.097
23	0.189	0.491	0.469	1.141*	0.469*	1.384	12.076	4.188	0.647	0.217	0.153	0.098
24	0.206	0.463	0.461*	1.045*	0.469	1.391	13.574	4.836	0.608	0.213	0.147	0.096
25	0.284	0.448	0.453*	0.962	0.469	1.584	12.310	5.246	0.555	0.204	0.138	0.097
26	0.232	0.425	0.441*	0.890	0.468	2.172	9.473	5.983	0.518	0.195	0.132	0.098
27	0.204	0.425	0.443*	0.840	0.462	2.673	6.639	5.938	0.505	0.191	0.126	0.109
28	0.190	0.427	0.479	0.785	0.517	3.178	5.210	5.018	0.491	0.182	0.123	0.116
29	0.189	0.433	0.453	0.744		2.616	5.404*	4.189	0.476	0.173	0.122	0.114
30	0.180	0.460	0.437	0.718		3.051	7.878*	3.487	0.453	0.171	0.122	0.110
31	0.449		0.426*	0.712		3.052		3.165		0.163	0.119	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	5.631	28.565	14.482	32.112	15.180	43.277	160.509	203.744	40.457	9.734	4.807	3.244
TOTAL FLOW (cms days)	0.159	0.809	0.410	0.909	0.430	1.226	4.546	5.770	1.146	0.276	0.136	0.092
TOTAL DEPTH (in)	0.291	1.478	0.749	1.662	0.785	2.239	8.305	10.542	2.093	0.504	0.249	0.168
TOTAL DEPTH (cm)	0.740	3.754	1.903	4.220	1.995	5.688	21.095	26.777	5.317	1.279	0.632	0.426

ANNUAL SUMMARY:
Sum of Mean Daily Flow 561.741 cfs = 15.909 cms
Total Depth 29.066 in = 73.828 cm
Maximum Instantaneous Flow 15.432 cfs = 0.437 cms on April 23 at 17.75 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 1
WATERSHED AREA: 460 ACRES (186 HECTARES)

WATER YEAR 1975
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.112	0.183	0.220	0.189	0.180*	0.316*	0.624*	1.038	4.538	0.649	0.239	0.184
2	0.113	0.183	0.226	0.192	0.179*	0.444*	0.622*	1.827	4.420	0.612	0.230	0.184
3	0.115	0.180	0.206	0.192	0.179*	0.406*	0.621*	3.148	3.792	0.571	0.225	0.174
4	0.116	0.178	0.223	0.188	0.179*	0.393	0.619*	2.611	3.042	0.553	0.221	0.168
5	0.126	0.179	0.213	0.184	0.180*	0.397	0.618*	1.969	2.625	0.520	0.215	0.163
6	0.130	0.181	0.202	0.183	0.180*	0.405	0.617*	1.622	2.441	0.497	0.192	0.156
7	0.128	0.240	0.199	0.183	0.180*	0.450	0.617*	1.483	2.183	0.470	0.181	0.152
8	0.124	0.270	0.193	0.180	0.180*	0.564	0.617*	1.805	1.896	0.450	0.179	0.148
9	0.162	0.214	0.191	0.178	0.180*	0.544	0.635*	2.871	1.669	0.422	0.174	0.146
10	0.187	0.209	0.192	0.174	0.179*	0.477	0.646*	5.832	1.513	0.413	0.171	0.148
11	0.168	0.201	0.196	0.171	0.179*	0.428	0.662*	7.289	1.361	0.406	0.167	0.146
12	0.161	0.201	0.190	0.171	0.182*	0.410	0.675*	7.703	1.231	0.395	0.165	0.145
13	0.159	0.200	0.186	0.170	0.181*	0.404	0.673*	9.974	1.123	0.397	0.162	0.144
14	0.156	0.196	0.182	0.170	0.182*	0.398	0.674*	12.921	1.004	0.378	0.162	0.169
15	0.159	0.191	0.181	0.171	0.183*	0.411	0.681*	14.877	0.916	0.371	0.160	0.144
16	0.156	0.187	0.183	0.171	0.182*	0.411	0.687*	13.449	0.831	0.364	0.161	0.152
17	0.155	0.187	0.183	0.174	0.181*	0.390	0.690*	11.494	1.123	0.375	0.185	0.145
18	0.154	0.211	0.187	0.207	0.181*	0.431*	0.717*	10.318	1.851	0.359	0.256	0.149
19	0.154	0.199	0.181	0.217	0.182*	0.565*	0.926*	8.257	1.625	0.339	0.258	0.148
20	0.155	0.202	0.182	0.215	0.182*	0.558*	0.943*	5.864	1.600	0.317	0.259	0.146
21	0.207	0.218	0.191	0.204	0.181*	0.554*	1.216*	5.310	1.354	0.300	0.214	0.139
22	0.198	0.224	0.183	0.202	0.182*	0.552*	1.786*	4.838	1.164	0.287	0.289	0.138
23	0.200	0.205	0.190	0.206	0.182*	0.551*	2.106*	4.775	1.025	0.245	0.414	0.137
24	0.205	0.203	0.195	0.208	0.196*	0.556*	1.595*	4.305	0.960	0.233	0.383	0.135
25	0.197	0.201	0.205	0.262	0.222*	0.560*	1.661	3.615	1.011	0.225	0.319	0.128
26	0.187	0.196	0.207	0.246*	0.248*	0.619*	1.367	3.371	0.937	0.221	0.289	0.127
27	0.178	0.193	0.207	0.225*	0.253*	0.635*	1.173	3.631	0.849	0.218	0.280	0.127
28	0.185	0.197	0.204	0.206*	0.264*	0.645*	1.030	4.049	0.796	0.216	0.251	0.125
29	0.186	0.198	0.199	0.187*		0.628*	0.930	4.354	0.739	0.222	0.197	0.126
30	0.176	0.208	0.187	0.179*		0.628*	0.928	4.668	0.688	0.244	0.184	0.124
31	0.177		0.188	0.181*		0.625*		4.728		0.240	0.181	
MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	4.983	6.034	6.069	5.987	5.338	15.356	27.356	173.994	50.309	11.511	6.961	4.417
TOTAL FLOW (cms days)	0.141	0.171	0.172	0.170	0.151	0.435	0.775	4.928	1.425	0.326	0.197	0.125
TOTAL DEPTH (in)	0.258	0.312	0.314	0.310	0.276	0.795	1.415	9.003	2.603	0.596	0.360	0.229
TOTAL DEPTH (cm)	0.655	0.793	0.798	0.787	0.702	2.018	3.595	22.867	6.612	1.513	0.915	0.581

ANNUAL SUMMARY:
Sum of Mean Daily Flow 318.316 cfs = 9.015 cms
Total Depth 16.471 in = 41.835 cm
Maximum Instantaneous Flow 17.026 cfs = 0.482 cms on May 14 at 17.00 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 1
WATERSHED AREA: 460 ACRES (186 HECTARES)

WATER YEAR 1976
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.120	0.366	0.439	0.488*	0.588	0.397	0.972	7.039	1.061	0.325	0.219	0.133
2	0.122	0.357	1.573	0.487*	0.606	0.391	0.845	8.458	0.952	0.318	0.200	0.129
3	0.123	0.406	0.731	0.485*	0.617	0.386	1.060	8.542	0.896	0.308	0.180	0.126
4	0.135	0.424	0.751	0.484*	0.600	0.388	1.974	8.690	0.832	0.299	0.184	0.125
5	0.131	0.389	0.924	0.484*	0.576	0.395	3.418	8.101*	0.765	0.287	0.175	0.119
6	0.232	0.370	0.715	0.482*	0.567	0.382	3.532	7.550*	0.714	0.279	0.153	0.144
7	0.417	0.449	1.501	0.482*	0.559	0.382	3.519	7.196*	0.678	0.280	0.154	0.132
8	0.257	0.398	1.679	0.482*	0.544	0.389	5.039	7.589*	0.650	0.275	0.180	0.129
9	0.214	0.347	1.456	0.482*	0.516	0.415	5.497	7.941*	0.644	0.268	0.165	0.127
10	0.197	0.339	1.236	0.482*	0.498	0.483	5.108	8.017	0.672	0.256	0.153	0.122
11	0.277	0.310	1.039	0.482*	0.487	0.569	5.497	7.074	0.875	0.247	0.152	0.186
12	0.358	0.297	0.894	0.488*	0.479	0.502	5.241	5.512	0.793	0.256	0.149	0.166
13	0.296	0.296	0.756	0.488*	0.471	0.481	4.526	5.015	0.831	0.250	0.143	0.147
14	0.244	0.307	0.693	0.488*	0.474	0.469	4.568	4.886	0.723	0.237	0.138	0.144
15	0.227	0.364	0.666	0.486*	0.467	0.456	4.200	4.337	0.660	0.225	0.247	0.140
16	0.218	0.482	0.617	0.483*	0.464	0.456	3.370	3.729	0.649	0.213	0.240	0.167
17	0.208	0.438	0.602	0.482*	0.455	0.464	2.985	3.502	0.638	0.245	0.202	0.179
18	0.202	0.387	0.607	0.484*	0.448	0.485	2.723	3.148	0.597	0.475	0.213	0.184
19	0.197	0.353	0.599	0.488*	0.440	0.491	2.510	2.824	0.555	0.317	0.195	0.175
20	0.197	0.333	0.577	0.476	0.430	0.483	2.513	2.453	0.529	0.262	0.175	0.159
21	0.257	0.328	0.563	0.467	0.425	0.481	2.484	2.137	0.578	0.237	0.164	0.151
22	0.287	0.340	0.555	0.469	0.421	0.494	2.555	1.980	0.558	0.222	0.177	0.155
23	0.251	0.307	0.536	0.470	0.416	0.491	2.536	1.867	0.513	0.211	0.213	0.158
24	0.235	0.284	0.515	0.474	0.400	0.488	3.287	1.765	0.497	0.247	0.183	0.149
25	0.237	0.269	0.493	0.466	0.393	0.483	4.558	1.599	0.468	0.226	0.174	0.146
26	0.275	0.263	0.483	0.459	0.404	0.473	3.537	1.456	0.437	0.213	0.183	0.145
27	0.262	0.264	0.483*	0.455	0.411	0.469	3.149	1.333	0.419	0.204	0.164	0.164
28	0.255	0.255	0.482*	0.457	0.404	0.464	3.061	1.279	0.396	0.192	0.154	0.171
29	0.279	0.250	0.483*	0.479	0.401	0.459	3.805	1.187	0.358	0.205	0.149	0.167
30	0.345	0.254	0.484*	0.519		0.485	5.305	1.092	0.336	0.202	0.140	0.167
31	0.369		0.488*	0.552		0.637		1.213		0.195	0.136	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	7.424	10.226	23.621	14.952	13.958	14.290	103.373	138.509	19.272	7.976	5.454	4.506
TOTAL FLOW (cms days)	0.210	0.290	0.669	0.423	0.395	0.405	2.928	3.923	0.546	0.226	0.154	0.128
TOTAL DEPTH (in)	0.384	0.529	1.222	0.774	0.722	0.739	5.349	7.167	0.997	0.413	0.282	0.233
TOTAL DEPTH (cm)	0.976	1.344	3.104	1.965	1.834	1.878	13.586	18.204	2.533	1.048	0.717	0.592

ANNUAL SUMMARY:
Sum of Mean Daily Flow 363.560 cfs = 10.296 cms
Total Depth 18.812 in = 47.781 cm
Maximum Instantaneous Flow 10.118 cfs = 0.287 cms on May 2 at 19.00 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 1
WATERSHED AREA: 460 ACRES (186 HECTARES)

WATER YEAR 1977
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.162	0.183	0.172*	0.171*	0.171*	0.171*	0.326*	0.185	0.271	0.128	0.073	0.089
2	0.176	0.182	0.172*	0.171*	0.171*	0.171*	0.443*	0.200	0.252	0.141	0.072	0.083
3	0.182	0.180	0.173*	0.171*	0.171*	0.172*	0.571*	0.208	0.232	0.150	0.070	0.080
4	0.179	0.179	0.171*	0.171*	0.172*	0.171*	0.709*	0.208	0.214	0.152	0.067	0.076
5	0.179	0.178	0.171*	0.171*	0.172*	0.172*	0.860*	0.202	0.195	0.134	0.064	0.072
6	0.176	0.176	0.171*	0.171*	0.171*	0.171*	1.022*	0.207	0.179	0.124	0.063	0.072
7	0.171	0.175	0.171*	0.173*	0.171*	0.171*	1.190*	0.217	0.366	0.115	0.067	0.072
8	0.170	0.175	0.171*	0.171*	0.171*	0.171*	1.366*	0.220	0.370	0.108	0.095	0.071
9	0.169	0.174	0.171*	0.171*	0.171*	0.171*	0.834	0.199	0.264	0.104	0.069	0.072
10	0.168	0.173	0.172*	0.171*	0.171*	0.171*	0.601	0.292	0.508	0.105	0.066	0.073
11	0.170	0.172	0.171*	0.171*	0.171*	0.170*	0.483	0.274	0.504	0.099	0.065	0.073
12	0.170	0.171	0.171*	0.171*	0.169*	0.171*	0.444	0.230	0.427	0.095	0.064	0.074
13	0.170	0.170	0.171*	0.171*	0.173*	0.173*	0.420	0.200	0.351	0.092	0.063	0.075
14	0.169	0.172	0.171*	0.173*	0.171*	0.171*	0.389	0.182	0.324	0.084	0.062	0.076
15	0.170	0.177	0.171*	0.171*	0.170*	0.171*	0.367	0.174	0.292	0.081	0.063	0.081
16	0.168	0.183	0.171*	0.171*	0.171*	0.169*	0.417	0.216	0.254	0.079	0.062	0.114
17	0.167	0.184	0.171*	0.171*	0.171*	0.171*	0.402	0.232	0.231	0.079	0.062	0.151
18	0.170	0.178	0.171*	0.171*	0.171*	0.171*	0.360	0.254	0.218	0.076	0.062	0.094
19	0.176	0.173	0.171*	0.171*	0.171*	0.171*	0.335	0.256	0.211	0.076	0.063	0.097
20	0.178	0.171	0.171*	0.171*	0.172*	0.172*	0.320	0.226	0.209	0.073	0.062	0.142
21	0.181	0.172	0.171*	0.173*	0.171*	0.171*	0.325	0.205	0.198	0.072	0.064	0.130
22	0.180	0.171	0.171*	0.171*	0.171*	0.171*	0.344	0.196	0.185	0.081	0.064	0.113
23	0.181	0.171	0.171*	0.171*	0.171*	0.171*	0.362	0.459	0.177	0.089	0.063	0.104
24	0.182	0.172	0.173*	0.171*	0.171*	0.172*	0.328	0.624	0.167	0.160	0.091	0.272
25	0.197	0.171*	0.171*	0.171*	0.171*	0.171*	0.306	0.658	0.158	0.123	0.115	0.184
26	0.191	0.174*	0.171*	0.171*	0.171*	0.171*	0.283	0.503	0.151	0.096	0.166	0.147
27	0.188	0.171*	0.171*	0.171*	0.171*	0.172*	0.254	0.523	0.146	0.085	0.111	0.127
28	0.186	0.172*	0.171*	0.172*	0.170*	0.171*	0.229	0.426	0.141	0.078	0.097	0.126
29	0.185	0.172*	0.171*	0.171*		0.171*	0.211	0.373	0.136	0.075	0.092	0.313
30	0.185	0.171*	0.171*	0.171*		0.171*	0.195	0.322	0.130	0.075	0.106	0.250
31	0.183		0.173*	0.171*		0.219*		0.292		0.074	0.104	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	5.477	5.246	5.308	5.307	4.788	5.351	14.693	8.961	7.460	3.102	2.406	3.503
TOTAL FLOW (cms days)	0.155	0.149	0.150	0.150	0.136	0.152	0.416	0.254	0.211	0.088	0.068	0.099
TOTAL DEPTH (in)	0.283	0.271	0.275	0.275	0.248	0.277	0.760	0.464	0.386	0.161	0.125	0.181
TOTAL DEPTH (cm)	0.720	0.690	0.698	0.698	0.629	0.703	1.931	1.178	0.980	0.408	0.316	0.460

ANNUAL SUMMARY:
Sum of Mean Daily Flow 71.605 cfs - 2.028 cms
Total Depth 3.705 in = 9.411 cm
Maximum Instantaneous Flow 2.219 cfs = 0.063 cms on June 7 at 21.00 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 1
WATERSHED AREA: 460 ACRES (186 HECTARES)

WATER YEAR 1978
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.191	0.133	0.345	0.383	0.302	0.417	8.320	4.922	1.103	0.341	0.264	0.176
2	0.158	0.162	0.450	0.380	0.300	0.427	5.867	4.845	1.070	0.351	0.250	0.172
3	0.136	0.147	0.800	0.374	0.295	0.434	4.404	4.398	1.042	0.379	0.236	0.167
4	0.120	0.142	0.691	0.371	0.288	0.427	3.483	3.690	1.007	0.372	0.222	0.170
5	0.107	0.217	0.540	0.361	0.300	0.431	2.918	3.086	0.953	0.365	0.228	0.182
6	0.101	0.215	0.468	0.356	0.336	0.454	2.573	2.731	0.903	0.354	0.214	0.277
7	0.097	0.178	0.424	0.350	0.335	0.485	2.414	2.610	0.839	0.345	0.202	0.345
8	0.097	0.157	0.384	0.345	0.331	0.561	2.400	2.630	0.786	0.332	0.186	0.390
9	0.097	0.144	0.359	0.341	0.328	0.838	2.647	2.966	0.736	0.322	0.183	0.270
10	0.096	0.143	0.340	0.337	0.320	0.897	3.397	3.524	0.874	0.311	0.179	0.298
11	0.094	0.140	0.330	0.328	0.318	0.974	4.174	3.648	0.829	0.273	0.183	0.289
12	0.093	0.137	0.313	0.321	0.310	0.878	3.778	3.252	0.707	0.253	0.184	0.280
13	0.095	0.140	0.318	0.313	0.307	0.788	3.468	3.152	0.654	0.240	0.318	0.271
14	0.094	0.138	3.010	0.329	0.301	0.731	3.293	3.393	0.613	0.251	0.267	0.246
15	0.092	0.258	5.975	0.345	0.300	0.692	3.528	3.525	0.583	0.260	0.234	0.232
16	0.093	0.275	2.579	0.336	0.297	0.701	4.302	2.977	0.557	0.253	0.256	0.226
17	0.091	0.221	1.738	0.333	0.298	1.015	3.561	2.582	0.528	0.250	0.245	0.228
18	0.091	0.196	1.291	0.326	0.298	1.775	3.165	2.367	0.540	0.244	0.235	0.237
19	0.090	0.186	1.034	0.323	0.309	2.216	3.210	2.227	0.512	0.242	0.221	0.236
20	0.090	0.180	0.948	0.316	0.339	2.728	3.380	2.196	0.467	0.256	0.211	0.236
21	0.089	0.172	0.944	0.313	0.396	3.352	3.050	2.254	0.446	0.246	0.205	0.229
22	0.088	0.167	0.884	0.309	0.456	4.412	2.709	2.186	0.422	0.234	0.245	0.237
23	0.092	0.157	0.727	0.303	0.503	5.158	2.563	2.061	0.397	0.335	0.238	0.245
24	0.094	0.152	0.586	0.302	0.498	4.279	2.725	2.047	0.392	0.342	0.211	0.243
25	0.102	0.204	0.541	0.305	0.468	3.756	3.533	1.918	0.496	0.327	0.191	0.232
26	0.130	1.248	0.499	0.304	0.450	4.496	5.006	1.804	0.424	0.312	0.192	0.231
27	0.111	0.687	0.473	0.301	0.435	6.222	5.423	1.755	0.402	0.296	0.187	0.236
28	0.111	0.469	0.468	0.305	0.417	6.710	4.845	1.628	0.367	0.302	0.181	0.235
29	0.122	0.398	0.441	0.307		8.488	4.596	1.486	0.337	0.286	0.177	0.235
30	0.144	0.368	0.412	0.301		9.906	4.582	1.350	0.376	0.273	0.175	0.235
31	0.134		0.390	0.302		8.994		1.220		0.257	0.181	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	3.341	7.531	28.704	10.220	9.835	83.644	113.311	84.427	19.361	9.207	6.701	7.286
TOTAL FLOW (cms days)	0.095	0.213	0.813	0.289	0.279	2.369	3.209	2.391	0.548	0.261	0.190	0.206
TOTAL DEPTH (in)	0.173	0.390	1.485	0.529	0.509	4.328	5.863	4.368	1.002	0.476	0.347	0.377
TOTAL DEPTH (cm)	0.439	0.990	3.772	1.343	1.293	10.993	14.892	11.096	2.545	1.210	0.881	0.958

ANNUAL SUMMARY:
Sum of Mean Daily Flow 383.568 cfs = 10.863 cms
Total Depth 19.847 in = 50.411 cm
Maximum Instantaneous Flow 11.105 cfs = 0.314 cms on March 29 at 20.00 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 1
WATERSHED AREA: 460 ACRES (186 HECTARES)

WATER YEAR 1979
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.231	0.223	0.254	0.219*	0.212*	0.223	0.639*	2.916*	0.533*	0.249*	0.134	0.163
2	0.234	0.222	0.240	0.227*	0.215*	0.223	0.595*	2.752*	0.980*	0.244*	0.133	0.146
3	0.233	0.222	0.242	0.233*	0.216*	0.222	0.580*	2.809*	0.473*	0.240*	0.131	0.142
4	0.235	0.222	0.345	0.235*	0.216*	0.220	0.572*	2.571*	0.447*	0.237*	0.130	0.144
5	0.235	0.224	0.300	0.221*	0.215*	0.218	0.603*	2.346*	0.429*	0.234*	0.127	0.140
6	0.234	0.227	0.257*	0.221*	0.214*	0.218	1.002*	2.265*	0.419*	0.231*	0.127	0.135
7	0.233	0.230	0.239*	0.222*	0.215*	0.219	1.445*	2.007*	0.415*	0.228*	0.126	0.133
8	0.229	0.248	0.238*	0.223*	0.209*	0.220	1.579*	1.745*	0.408*	0.223*	0.139	0.130
9	0.229	0.245	0.246*	0.222*	0.205*	0.222	1.981*	1.630*	0.393*	0.219*	0.138	0.131
10	0.227	0.233	0.250*	0.224*	0.204*	0.223	1.948*	1.689*	0.371*	0.216*	0.131	0.131
11	0.230	0.262	0.261*	0.268*	0.204*	0.239*	1.397*	1.736*	0.356*	0.213*	0.126	0.131
12	0.224	0.239	0.255*	0.255*	0.205*	0.277*	1.077*	1.742*	0.343*	0.210*	0.138	0.128
13	0.219	0.238	0.246*	0.224*	0.206*	0.319*	0.909*	1.713*	0.331*	0.207*	0.228	0.125
14	0.222	0.242	0.242*	0.220*	0.205*	0.363*	0.866*	1.725*	0.318*	0.203*	0.220	0.125
15	0.220	0.253	0.243*	0.221*	0.204*	0.409*	1.146*	1.794*	0.306*	0.199*	0.170	0.123
16	0.220	0.271	0.239*	0.220*	0.203*	0.456*	1.693*	1.859*	0.310*	0.196*	0.146	0.119
17	0.220	0.261	0.237*	0.219*	0.205*	0.501*	2.729*	1.699*	0.334*	0.191*	0.150	0.121
18	0.216	0.248	0.252*	0.217*	0.208*	0.548*	2.375*	1.580*	0.352*	0.186*	0.170	0.124
19	0.217	0.252	0.242*	0.216*	0.210*	0.598*	1.837*	1.314*	0.356*	0.180*	0.177	0.120
20	0.216	0.252	0.236*	0.214*	0.216*	0.651*	1.636*	1.218*	0.329*	0.176*	0.148	0.115
21	0.216	0.251	0.233	0.219*	0.217*	0.703*	1.683*	1.047*	0.317*	0.172*	0.150	0.112
22	0.215	0.254	0.233	0.217*	0.215*	0.734*	1.891*	0.937*	0.329*	0.167*	0.148	0.109
23	0.218	0.249	0.232	0.214*	0.215*	0.726*	2.224*	0.857*	0.319*	0.162*	0.185	0.106
24	0.219	0.248	0.231	0.219*	0.222*	0.788*	2.240*	0.887*	0.309*	0.156*	0.195	0.106
25	0.220	0.247	0.226	0.216*	0.226*	0.812*	2.338*	0.783*	0.299*	0.150	0.157	0.126
26	0.222	0.242	0.225	0.212*	0.224*	0.866*	2.686*	0.727*	0.290*	0.141	0.151	0.166
27	0.221	0.251	0.229*	0.211*	0.222*	0.967*	3.466*	0.694*	0.280*	0.143	0.170	0.137
28	0.221	0.267	0.229*	0.210*	0.224*	1.079*	3.896*	0.646*	0.270*	0.139	0.172	0.131
29	0.220	0.260	0.216*	0.209*		1.253*	4.138*	0.603*	0.260*	0.140	0.159	0.130
30	0.220	0.268*	0.210*	0.208*		1.137*	3.645*	0.588*	0.252*	0.138	0.177	0.130
31	0.221		0.217*	0.208*		0.767*		0.565*		0.136	0.188	
MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	6.933	7.354	7.547	6.865	5.953	16.401	54.816	47.443	11.129	5.924	4.840	3.877
TOTAL FLOW (cms days)	0.196	0.208	0.214	0.194	0.169	0.464	1.552	1.344	0.315	0.168	0.137	0.110
TOTAL DEPTH (in)	0.359	0.381	0.391	0.355	0.308	0.849	2.836	2.455	0.576	0.307	0.250	0.201
TOTAL DEPTH (cm)	0.911	0.967	0.992	0.902	0.782	2.155	7.204	6.235	1.463	0.779	0.636	0.510

ANNUAL SUMMARY:
Sum of Mean Daily Flow 179.084 cfs = 5.072 cms
Total Depth 9.266 in = 23.536 cm
Maximum Instantaneous Flow 4.659 cfs = 0.132 cms on April 30 at 5.79 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 1
WATERSHED AREA: 460 ACRES (186 HECTARES)

WATER YEAR 1980
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.126	0.254	0.206*	0.255	0.338*	0.957*	0.649	5.353	1.993	0.558	0.231	0.228
2	0.125	0.241	0.203	0.249	0.333*	0.943*	0.644	5.302	2.096*	0.573	0.228	0.278
3	0.125	0.234	0.278	0.249	0.335*	0.902*	0.634	5.032	1.726*	0.570	0.217	0.255
4	0.127	0.244	0.284	0.247	0.304*	0.888*	0.631	4.685	1.525*	0.535	0.237	0.239
5	0.127	0.257	0.260	0.247	0.297*	0.843*	0.657	4.499*	1.934*	0.510	0.267	0.237
6	0.126	0.243	0.254	0.244	0.297*	0.790*	0.692	5.258*	2.065*	0.494	0.268	0.233
7	0.125	0.232	0.251	0.242	0.297*	0.750*	0.685	5.799*	1.822*	0.470	0.266	0.232
8	0.124	0.229	0.267	0.244	0.296*	0.711*	0.673	5.009*	1.623*	0.467	0.263	0.235
9	0.127	0.228	0.289	0.245	0.297*	0.687*	0.699	4.789*	1.506*	0.466	0.261	0.185
10	0.128	0.223	0.320	0.247	0.304*	0.698*	0.732	4.333*	1.415*	0.433	0.261	0.295
11	0.128	0.220	0.317	0.249	0.316*	0.682*	0.762	3.795*	1.306*	0.421	0.258	0.368
12	0.127	0.216	0.311	0.339	0.327*	0.656*	1.130	3.197*	1.353*	0.415	0.246	0.255
13	0.128	0.216	0.304	0.773	0.332*	0.642*	2.159	2.737*	1.182*	0.414	0.249	0.361
14	0.128	0.217	0.295	1.964	0.328*	0.661*	3.210	2.479*	1.157*	0.422	0.250	0.309
15	0.239	0.215	0.285	1.345	0.327*	0.620*	4.197	2.429*	1.129*	0.423	0.374	0.258
16	0.188	0.214	0.276	0.888	0.325*	0.599*	4.366	2.388*	0.996*	0.393	0.301	0.228
17	0.194	0.219	0.273	0.716	0.337*	0.594*	6.159*	2.170*	0.920*	0.375	0.262	0.215
18	0.263	0.222	0.268	0.615	0.574*	0.593*	8.313*	1.993*	0.885*	0.368	0.280	0.283
19	0.586	0.217*	0.266	0.561	1.114*	0.583*	10.160*	1.745*	0.822*	0.365	0.277	0.280
20	0.316	0.213	0.266	0.532	1.032*	0.589*	12.225	1.532*	0.775*	0.355	0.262	0.310
21	0.291	0.209	0.265	0.503	0.872*	0.590*	11.672	1.467*	0.721*	0.334	0.253	0.349
22	0.298	0.215	0.265	0.482	0.755*	0.610*	11.498	1.339*	0.700*	0.305	0.237	0.292
23	0.418	0.213	0.258	0.467	0.667*	0.625*	11.832	1.584*	0.704*	0.290	0.233	0.271
24	0.399	0.204	0.258	0.453	0.596*	0.624*	10.671	1.391*	0.683	0.280	0.224	0.260
25	0.428	0.203	0.250	0.416*	0.562*	0.636*	8.623	1.716*	0.630	0.273	0.222	0.251
26	0.525	0.202	0.245	0.381*	0.593*	0.659*	8.342*	2.212	0.607	0.268	0.218	0.245
27	0.364	0.203	0.246	0.370*	0.747*	0.668*	8.567*	2.408	0.595	0.267	0.223	0.241
28	0.328	0.208	0.245	0.358*	0.904*	0.647	8.328*	2.403	0.574	0.251	0.225	0.234
29	0.296	0.210	0.250	0.353*	0.922*	0.655	7.536	2.334	0.552	0.248	0.219	0.235
30	0.277	0.209	0.250	0.346*		0.664	5.776	2.228	0.548	0.240	0.218	0.234
31	0.264		0.266	0.341*		0.658		1.989		0.238	0.224	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	7.447	6.631	8.270	14.921	14.728	21.427	152.222	95.593	34.545	12.021	7.754	7.894
TOTAL FLOW (cms days)	0.211	0.188	0.234	0.423	0.417	0.607	4.311	2.707	0.978	0.340	0.220	0.224
TOTAL DEPTH (in)	0.385	0.343	0.428	0.772	0.762	1.109	7.876	4.946	1.787	0.622	0.401	0.408
TOTAL DEPTH (cm)	0.979	0.872	1.087	1.961	1.936	2.816	20.006	12.564	4.540	1.580	1.019	1.038

ANNUAL SUMMARY:
Sum of Mean Daily Flow 383.455 cfs = 10.859 cms
Total Depth 19.841 in = 50.396 cm
Maximum Instantaneous Flow 15.374 cfs = 0.435 cms on April 20 at 17.40 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 1
WATERSHED AREA: 460 ACRES (186 HECTARES)

WATER YEAR 1981
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.229	0.227	0.265	1.390	0.520	1.277	1.573	2.638	0.906	0.466	0.231	0.180
2	0.226	0.229	0.321*	1.204	0.629	1.296	1.501	2.368	0.890	0.447	0.227	0.182
3	0.227	0.229	0.622	1.059	0.459	1.310	1.436	2.067	0.876	0.428	0.223	0.181
4	0.224	0.229	0.860	0.949	0.448	1.291	1.358	1.844	0.833	0.410	0.221	0.180
5	0.224	0.227	0.638	0.864	0.451	1.236	1.379	1.644	0.797	0.397	0.219	0.179
6	0.222	0.321	0.508*	0.807*	0.449	1.186	1.416	1.482	0.781	0.544	0.217	0.178
7	0.219	0.779	0.550*	0.771*	0.428	1.187	1.360	1.364	0.828	0.504	0.213	0.178
8	0.220	0.536	0.469	0.735*	0.419	1.194	1.289	1.276	1.259	0.442	0.208	0.178
9	0.219	0.367	0.407	0.701*	0.430	1.209	1.280	1.170*	1.133	0.414	0.207	0.169
10	0.221	0.325	0.406	0.681	0.446	1.235	1.245	1.217*	0.974	0.392	0.207	0.166
11	0.221	0.305	0.403	0.651	0.674	1.264	1.235	1.151*	0.884	0.378	0.203	0.165
12	0.294	0.301	0.392	0.625	0.460	1.315	1.184	1.053*	0.905	0.364	0.199	0.165
13	0.263	0.283	0.386	0.595	0.472	1.350	1.146	0.991*	0.899	0.352	0.198	0.165
14	0.245	0.280*	0.388	0.568	0.577	1.381	1.222	0.985*	0.877	0.345	0.196	0.165
15	0.241	0.274*	0.393	0.544	0.504	1.423	1.566	1.168*	0.828	0.337	0.196	0.164
16	0.231	0.266	0.455	0.522	0.952	1.497	1.936	1.073*	0.814	0.326	0.195	0.162
17	0.230	0.259	0.502	0.510	1.486	1.410	2.168*	0.977*	0.798	0.318	0.193	0.160
18	0.229	0.255	0.500	0.498	1.239	1.333	2.616*	0.914*	0.748	0.309	0.191	0.159
19	0.228	0.254	0.469	0.486	2.372	1.277	3.952	0.937*	0.738	0.301	0.193	0.159
20	0.226	0.254	0.448	0.476	2.259	1.279*	6.198	1.052*	0.707	0.295	0.202	0.158
21	0.236	0.255*	0.465	0.470	1.745	1.310*	5.742	1.150	0.669	0.288	0.192	0.160
22	0.237	0.253	0.931	0.468	1.543	1.322*	4.398	1.104	0.639	0.281	0.191	0.161
23	0.237	0.246*	0.768	0.524	1.473	1.347*	3.906	1.046	0.617	0.275	0.190	0.162
24	0.240	0.248*	0.643	0.543	1.489	1.315*	4.235	1.001	0.590	0.268	0.186	0.162
25	0.254	0.250*	1.460	0.505	1.505	1.388	4.114	1.426	0.564	0.267	0.184	0.202
26	0.296	0.252*	6.404	0.484*	1.376	1.608	4.052	1.400	0.540	0.265	0.182	0.207
27	0.269*	0.258	4.881	0.474	1.310	1.645	3.843	1.194	0.523	0.256	0.180	0.210
28	0.246	0.263	3.619	0.469	1.278	1.650	3.294	1.078	0.507	0.251	0.178	0.234
29	0.241	0.266	2.381	0.459		1.719	2.984	0.989	0.492	0.247	0.177	0.198
30	0.239	0.268	1.785	0.465		1.645	2.803	1.016	0.481	0.244	0.176	0.188
31	0.235		1.561	0.454		1.565		0.984		0.239	0.179	

MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	7.368	8.759	34.281	19.951	27.392	42.464	76.433	39.759	23.100	10.650	6.153	5.278
TOTAL FLOW (cms days)	0.209	0.248	0.971	0.565	0.776	1.203	2.165	1.126	0.654	0.302	0.174	0.149
TOTAL DEPTH (in)	0.381	0.453	1.774	1.032	1.417	2.197	3.955	2.057	1.195	0.551	0.318	0.273
TOTAL DEPTH (cm)	0.968	1.151	4.505	2.622	3.600	5.581	10.045	5.225	3.036	1.400	0.809	0.694

ANNUAL SUMMARY:
Sum of Mean Daily Flow 301.589 cfs = 8.541 cms
Total Depth 15.605 in = 39.637 cm
Maximum Instantaneous Flow 9.106 cfs = 0.258 cms on December 26 at 7.21 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 1
WATERSHED AREA: 460 ACRES (186 HECTARES)

WATER YEAR 1982
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.181	0.274	0.400	0.477	0.443*	1.108	1.211	10.153	3.002	0.673	0.299	0.185
2	0.181	0.265	0.407	0.454	0.444*	1.259	1.155	13.254	2.914	0.668	0.292	0.182
3	0.196	0.258	0.365	0.447	0.444*	1.175	1.124	12.584	2.735	0.672	0.290	0.175
4	0.193	0.252	0.346	0.469	0.436*	1.094	1.072	9.785	2.594	0.635	0.283	0.177
5	0.197	0.250	0.346	0.435	0.423*	1.036	1.044	7.816	2.407	0.632	0.278	0.172
6	0.196	0.251	0.381	0.414	0.420*	1.002	1.024	7.926	2.177	0.608	0.268	0.167
7	0.267	0.248	0.405	0.405	0.414*	0.985	0.979	8.476	2.024	0.616	0.262	0.165
8	0.224	0.249	0.436	0.404	0.403*	0.988	0.937	7.884	1.882	0.625	0.271	0.162
9	0.223	0.247	0.496	0.402	0.401*	0.989	0.928	6.966	1.791	0.609	0.273	0.157
10	0.311	0.246	0.647	0.400	0.392*	0.983	0.930	6.591	1.778	0.564	0.263	0.165
11	0.342	0.247	0.584	0.395	0.385*	1.060	2.031	6.438	1.750	0.532	0.258	0.173
12	0.264	0.411	0.532	0.394*	0.374*	1.107	3.076	6.890	1.753	0.505	0.263	0.238
13	0.244	0.670	0.489	0.409*	0.367*	1.100	2.845	8.096	1.715	0.486	0.259	0.240
14	0.230	0.751	0.463	0.413*	0.586*	1.083	2.992	9.879	1.598	0.470	0.251	0.224
15	0.218	0.550	0.450	0.417*	0.725*	1.068	2.655	10.689	1.518	0.457	0.240	0.223
16	0.211	1.576	0.438	0.431*	1.271*	1.039	2.330	11.277	1.435	0.447	0.234	0.211
17	0.204	1.405	0.425	0.445*	1.108*	1.013	2.174	10.271	1.308	0.438	0.227	0.204
18	0.203	0.995	0.420	0.437*	1.004	1.004	2.024	10.152	1.196	0.427	0.219*	0.199
19	0.201	0.713	1.230	0.439*	0.925	0.969	1.871	8.454	1.106	0.413	0.205*	0.263
20	0.202	0.590	2.422	0.441*	1.078	0.940	1.764	7.748	1.002	0.399	0.212	0.336
21	0.201	0.699	1.298	0.440*	2.638	0.912	1.915	8.152	0.927	0.387	0.200	0.259
22	0.200	1.039	0.990	0.437*	3.267	0.896	2.845	8.346	0.904*	0.376	0.192	0.226
23	0.200	0.824	0.838	0.454*	4.516	0.877	4.889	7.899	0.885*	0.366	0.191	0.216
24	0.200	0.706	0.760	0.454*	1.798	0.871	6.620	7.309	0.784	0.361	0.186	0.226
25	0.201	0.615	0.706	0.445*	1.493	0.985	7.280	7.656*	0.790	0.345	0.184	0.256
26	0.231	0.561	0.653	0.449*	1.298	1.298	7.202	7.408*	0.723	0.332	0.177	0.433
27	0.225	0.515	0.612	0.446*	1.164	1.510	8.393	5.655*	0.711	0.327	0.174	0.287
28	0.274	0.517	0.581	0.446*	1.077	1.405	8.626	4.545	0.741	0.337	0.175	0.305
29	0.277	0.474	0.544	0.446*		1.352	7.957	3.821	0.711	0.329	0.183	0.427
30	0.255	0.423	0.517	0.445*		1.300	8.100	3.370	0.662	0.313	0.219	0.366
31	0.266		0.497	0.444*		1.267		3.125		0.302	0.197	

MONTHLY SUMMARY:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	7.015	16.823	19.676	13.433	29.295	33.677	97.991	248.613	45.521	14.653	7.223	7.019
TOTAL FLOW (cms days)	0.199	0.476	0.557	0.380	0.830	0.954	2.775	7.041	1.289	0.415	0.205	0.199
TOTAL DEPTH (in)	0.363	0.870	1.018	0.695	1.516	1.743	5.070	12.864	2.355	0.758	0.374	0.363
TOTAL DEPTH (cm)	0.922	2.211	2.586	1.765	3.850	4.426	12.879	32.674	5.983	1.926	0.949	0.923

ANNUAL SUMMARY:
Sum of Mean Daily Flow 540.939 cfs = 15.319 cms
Total Depth 27.990 in = 71.094 cm
Maximum Instantaneous Flow 17.020 cfs = 0.482 cms on May 2 at 18.21 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 2
WATERSHED AREA: 291 ACRES (117 HECTARES)

WATER YEAR 1965
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.160	0.201	0.315	0.441	0.619	0.893*	1.646	5.537	1.646	0.341	0.169	0.162
2	0.155	0.265	0.309	0.459	0.619	0.929*	1.804	4.154	1.507	0.345	0.188	0.158
3	0.141	0.202	0.284	0.467	0.556	0.966*	1.325	3.636	1.409	0.319	0.190	0.155
4	0.131	0.190	0.267	0.469	0.477	1.002*	1.187	3.237	1.290	0.299	0.182	0.155
5	0.132	0.180	0.255	0.386	0.450	1.039*	1.284	2.780	1.155	0.282	0.175	0.162
6	0.133	0.173	0.255	0.289	0.448	1.077*	1.336	2.330	1.054	0.266	0.170	0.169
7	0.128	0.170	0.267	0.265	0.445	1.114*	1.252	2.122	0.963	0.254	0.162	0.201
8	0.161	0.169	0.272	0.260	0.445	1.157*	1.396	[illegible]	0.875	0.255	0.156	0.211
9	0.142	0.170	0.272	0.263	0.451	1.125	1.610	[illegible]	0.798	0.283	0.164	0.190
10	0.140	0.186	0.272	0.267	0.463	1.289	1.440	[illegible]	0.716	0.276	0.160	0.176
11	0.139	0.181	0.272	0.268	0.478	1.302	1.334	3.048	0.651	0.272	0.165	0.173
12	0.138	0.184	0.276	0.269	0.491	1.120	1.582	3.186	0.621	0.270	0.262	0.165
13	0.137	0.176	0.283	0.271	0.499	1.093	2.289	3.734	0.690	0.259	0.219	0.171
14	0.137	0.176	0.291	0.227	0.503	1.101	3.062	4.009	0.637	0.245	0.176	0.179
15	0.227	0.184	0.296	0.181	0.507	1.128	3.694	3.586	0.604	0.238	0.167	0.216
16	0.183	0.187	0.298	0.181	0.511	1.177	3.924	3.641	0.636	0.223	0.164	0.202
17	0.162	0.189	0.311	0.189	0.513	1.161	3.249	3.246	0.614	0.220	0.156	0.194
18	0.157	0.188	0.330	0.201	0.530*	1.163	2.626	2.832	0.565	0.214	0.156	0.195
19	0.153	0.188	0.338	0.206	0.560*	1.176	4.881*	2.690	0.518	0.209	0.239	0.193
20	0.149	0.189	0.342	0.206	0.591*	1.196	9.483*	2.844	0.484	0.229	0.228	0.191
21	0.146	0.190	0.346	0.212	0.623*	1.208	10.097*	2.662	0.458	0.222	0.246	0.190
22	0.145	0.191	3.255	0.219	0.655*	1.212	8.241*	2.880	0.435	0.207	0.221	0.185
23	0.145	0.193	5.648	0.219	0.687*	1.212	7.473*	2.905	0.443	0.199	0.205	0.183
24	0.145	0.306	3.001	0.212	0.721*	1.219	5.702	2.588	0.447	0.187	0.185	0.183
25	0.145	0.826	1.832	0.207	0.754*	1.236	5.357	2.387	0.411	0.182	0.186	0.182
26	0.154	0.425	1.111	0.207	0.787*	1.251	5.458	2.260	0.408	0.176	0.185	0.178
27	0.157	0.322	0.687	0.206	0.823*	1.256	5.687	2.170	0.389	0.176	0.182	0.176
28	0.154	0.285	0.496	0.206	0.859*	1.258	5.367	2.126	0.370	0.192	0.174	0.182
29	0.151	0.267	0.441	0.251*		1.260	5.339	2.074	0.342	0.183	0.172	0.181
30	0.158	0.293	0.433	0.526*		1.260	5.480	[illegible]	0.309	0.172	0.172	0.181
31	0.158		0.432	0.637		1.272		[illegible]		0.170	0.166	

MONTHLY SUMMARY:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	4.663	7.040	23.499	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TOTAL FLOW (cms days)	0.132	0.200	0.665	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TOTAL DEPTH (in)	0.381	0.576	1.921	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TOTAL DEPTH (cm)	0.969	[illegible]	4.880	[illegible]	3.337	[illegible]	[illegible]	[illegible]	[illegible]	1.528	[illegible]	[illegible]

ANNUAL SUMMARY:
Sum of Mean Daily Flow 342 285 cfs = 9.694 cms
Total Depth 27 996 in = 71.111 cm
Maximum Instantaneous Flow [illegible] cfs = 0 414 cms on [illegible] 22 at 21 00 hours

* Indicates some data were estimated during this day

SILVER CREEK STUDY AREA
WATERSHED: 2
WATERSHED AREA: 291 ACRES (117 HECTARES)

WATER YEAR 1966
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.181	0.177	0.257	0.296*	0.204*	0.155*	2.946	0.772	0.280	0.133	0.067	0.067
2	0.179	0.176	0.258	0.296*	0.204*	0.156*	2.712	0.980	0.256	0.147	0.064	0.064
3	0.179	0.174	0.218	0.296*	0.204*	0.155*	2.075	1.165	0.258	0.138	0.067	0.062
4	0.177	0.179	0.215	0.296*	0.204*	0.156*	1.754	1.297	0.265	0.124	0.071	0.061
5	0.177	0.178	0.222	0.296*	0.204*	0.159*	1.722	1.354	0.251	0.121	0.068	0.063
6	0.178	0.176	0.227	0.296*	0.202*	0.161*	1.867	1.272	0.242	0.118	0.065	0.059
7	0.178	0.175	0.221	0.278*	0.197*	0.160*	2.046	1.089	0.236	0.110	0.064	0.059
8	0.178	0.174	0.214	0.231*	0.194*	0.151*	2.225	0.986	0.233	0.105	0.064	0.055
9	0.172	0.174	0.209	0.187*	0.193*	0.149*	2.155	0.957	0.258	0.103	0.063	0.055
10	0.172	0.177	0.206	0.172*	0.193*	0.179*	2.038	0.852	0.258	0.101	0.064	0.054
11	0.172	0.191	0.204	0.170*	0.192*	0.199*	1.849	0.721	0.242	0.094	0.067	0.055
12	0.173	0.193	0.198	0.170*	0.191*	0.190	1.621	0.629	0.231	0.089	0.064	0.064
13	0.172	0.201	0.193	0.172*	0.191*	0.285*	1.458	0.550	0.219	0.085	0.063	0.073
14	0.181	0.268	0.204	0.173*	0.191*	0.507	1.374	0.544	0.205	0.083	0.067	0.115
15	0.273	0.256	0.211	0.173*	0.191*	0.524	1.511	0.498	0.197	0.079	0.062	0.145
16	0.211	0.224	0.220	0.172*	0.193*	0.455	1.774	0.455	0.195	0.076	0.059	0.104
17	0.204	0.218	0.227	0.172*	0.197*	0.392*	1.601	0.401*	0.183	0.072	0.058	0.087
18	0.201	0.228	0.237	0.173*	0.199*	0.377*	1.300	0.325*	0.175	0.072	0.057	0.085
19	0.255	0.219	0.246	0.174*	0.199*	0.377*	1.108	0.298*	0.168	0.070	0.059	0.098
20	0.213	0.210	0.255	0.177*	0.198*	0.377*	0.960	0.268	0.166	0.074	0.060	0.090
21	0.203	0.207	0.269	0.181*	0.196*	0.377*	0.854	0.269	0.170	0.072	0.060	0.082
22	0.196	0.201	0.282	0.186*	0.192*	0.379*	0.769	0.359	0.173	0.068	0.059	0.077
23	0.192	0.205	0.286	0.190*	0.189*	0.382*	0.769	0.330	0.188	0.065	0.054	0.072
24	0.190	0.200	0.288	0.191*	0.187*	0.404*	0.868	0.323	0.191	0.065	0.050	0.073
25	0.188	0.196	0.289	0.193*	0.184*	0.682*	1.033	0.308	0.175	0.065	0.049	0.080
26	0.187	0.195	0.290	0.197*	0.182*	1.275*	1.003	0.282	0.164	0.069	0.066	0.092
27	0.186	0.200	0.291	0.201*	0.177*	1.727	0.825	0.252	0.155	0.074	0.074	0.090
28	0.186	0.203	0.292	0.203*	0.163*	2.136	0.753	0.254	0.147	0.073	0.066	0.085
29	0.180	0.244	0.293	0.204*		2.502	0.703	0.240	0.141	0.070	0.074	0.082
30	0.178	0.254	0.293	0.204*		2.744	0.685	0.232	0.136	0.070	0.073	0.079
31	0.177		0.295	0.204*		3.198		0.262		0.071	0.070	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	5.890	6.071	7.611	6.518	5.412	21.071	44.357	18.525	6.158	2.757	1.971	2.330
TOTAL FLOW (cms days)	0.167	0.172	0.216	0.185	0.153	0.597	1.256	0.525	0.174	0.078	0.056	0.066
TOTAL DEPTH (in)	0.482	0.497	0.623	0.533	0.443	1.723	3.628	1.515	0.504	0.225	0.161	0.191
TOTAL DEPTH (cm)	1.224	1.261	1.581	1.354	1.124	4.378	9.215	3.849	1.279	0.573	0.409	0.484

ANNUAL SUMMARY:
Sum of Mean Daily Flow 128.671 cfs = 3.644 cms
Total Depth 10.524 in = 26.732 cm
Maximum Instantaneous Flow 4.171 cfs = 0.118 cms on March 31 at 17.00 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 2
WATERSHED AREA: 291 ACRES (117 HECTARES)

WATER YEAR 1967
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.083	0.116	0.302	0.197*	0.365	0.440	0.506	0.741	1.515	0.250	0.115	0.178*
2	0.121	0.115	0.339	0.194	0.318	0.395	0.541	0.806	1.267	0.232	0.109	0.177*
3	0.103	0.118	0.303	0.191	0.293	0.365	0.728	0.990	1.104	0.234	0.105	0.176*
4	0.097	0.117	0.271	0.188	0.277	0.357	0.900	1.444	0.985	0.228	0.103	0.182*
5	0.095	0.120	0.268	0.186	0.266	0.353	0.817	1.934	0.931	0.213	0.101	0.188*
6	0.091	0.153	0.242	0.184	0.264	0.355*	0.795	2.433	0.924	0.210	0.098	0.192*
7	0.089	0.145	0.232	0.182	0.265	0.376*	0.996	3.496	0.879	0.206	0.101	0.204*
8	0.094	0.132	0.215	0.180	0.267	0.384*	1.210	4.275*	0.826	0.199	0.099	0.212*
9	0.092	0.130	0.213	0.177	0.268	0.376*	1.327	4.508	0.787	0.196	0.096	0.210*
10	0.091	0.134	0.205	0.172	0.261	0.357	1.369	3.900	0.746	0.189	0.092	0.205*
11	0.091	0.133	0.197	0.167	0.252	0.330	1.292	2.839	0.711	0.180	0.091	0.262*
12	0.137	0.174	0.198	0.165	0.248	0.310	1.397	2.197	0.705	0.172	0.085	0.280*
13	0.120	0.202	0.196	0.179	0.244	0.297	1.450	1.828	0.653	0.169	0.083	0.226*
14	0.119	0.240	0.198	0.204	0.232	0.285	1.391	1.889	0.608	0.165	0.080	0.210*
15	0.117	0.278	0.192	0.198	0.227	0.277	1.195	2.722	0.569	0.159	0.077	0.205*
16	0.116	0.561	0.193	0.193	0.227	0.363	1.039	3.690	0.534	0.165	0.129*	0.203*
17	0.115	0.314	0.194	0.186	0.232	0.864	0.936	4.425*	0.515	0.215	0.207*	0.201*
18	0.111	0.234	0.208	0.184	0.227	0.842	0.900	4.304	0.487	0.175	0.197*	0.198*
19	0.113	0.195	0.227	0.184	0.221	0.656	0.883	3.950	0.452	0.159	0.189*	0.196*
20	0.110	0.291	0.235	0.184	0.222	0.572	0.825	3.519	0.464	0.152	0.181*	0.194*
21	0.115	0.321	0.222	0.187	0.223	0.522	0.764	3.567	0.515	0.149	0.199*	0.192*
22	0.124	0.259	0.215	0.182	0.223	0.525	0.752	3.511	0.449	0.143	0.215*	0.084
23	0.139	0.213	0.216	0.180	0.222	0.639	0.805	3.255	0.416	0.136	0.196*	0.075
24	0.138	0.192	0.216	0.182	0.229*	0.666	0.829	2.667	0.387	0.130	0.179*	0.077
25	0.133	0.180	0.215	0.182	0.263	0.625	0.841	2.181	0.362	0.126	0.171*	0.076
26	0.128	0.171	0.214	0.180	0.270*	0.613	0.873	1.860	0.338	0.122	0.173*	0.073
27	0.123	0.165	0.213	0.185	0.317*	0.585	0.901	1.714	0.331	0.122	0.180*	0.073
28	0.119	0.164	0.210	0.232*	0.419	0.603	0.882	1.625	0.312	0.119	0.182*	0.071
29	0.115	0.243	0.207	0.599*		0.601	0.821	1.712	0.292	0.120	0.180*	0.069
30	0.118	0.251	0.205	0.630*		0.560	0.769	1.603	0.272	0.121	0.179*	0.254
31	0.117		0.202	0.453		0.529		1.352		0.125	0.180*	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	3.476	6.056	6.965	6.885	7.342	15.022	28.733	80.936	19.337	5.280	4.373	5.140
TOTAL FLOW (cms days)	0.098	0.171	0.197	0.195	0.208	0.425	0.814	2.292	0.548	0.150	0.124	0.146
TOTAL DEPTH (in)	0.284	0.495	0.570	0.563	0.601	1.229	2.350	6.620	1.582	0.432	0.358	0.420
TOTAL DEPTH (cm)	0.722	1.258	1.447	1.430	1.525	3.121	5.969	16.815	4.017	1.097	0.909	1.068

ANNUAL SUMMARY:
Sum of Mean Daily Flow 189.544 cfs = 5.368 cms
Total Depth 15.503 in = 39.378 cm
Maximum Instantaneous Flow 5.780 cfs = 0.164 cms on May 17 at 19.00 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 2
WATERSHED AREA: 291 ACRES (117 HECTARES)

WATER YEAR 1968
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.186	0.190	0.165*	0.217*	0.184	1.444	1.160	1.153	0.430	0.174	0.066	0.107
2	0.200	0.176	0.165*	0.206	0.184	1.481	1.269	1.051	0.408	0.165	0.065	0.111
3	0.421	0.167	0.168	0.198	0.187	1.482	1.204	1.016	0.400	0.152	0.062	0.106
4	0.172	0.162	0.171*	0.191	0.193	1.531	1.136	1.024	0.380	0.140	0.065	0.103
5	0.159	0.159	0.175	0.187*	0.196	1.562	1.225	0.990	0.367	0.135	0.062	0.095
6	0.147	0.154	0.167	0.185*	0.230	1.388	1.120	0.872	0.409	0.125	0.059	0.094
7	0.132	0.154	0.165*	0.185*	0.294	1.199	1.018	0.804	0.418	0.121	0.058	0.089
8	0.122	0.156	0.164*	0.184	0.302	1.031	0.946	0.761	0.366	0.136	0.057	0.087
9	0.117	0.174	0.163*	0.181*	0.339	0.916	0.942	0.770	0.366	0.119	0.058	0.085
10	0.115	0.200	0.162*	0.181	0.376	0.835	1.127	0.790	0.361	0.110	0.123	0.087
11	0.124	0.260	0.182*	0.175	0.413	0.770	1.451	0.790	0.331	0.103	0.074	0.095
12	0.145	0.315	0.203*	0.172*	0.423	0.723	1.358	0.894	0.305	0.114	0.070	0.095
13	0.139	0.281	0.201*	0.171*	0.374	0.733	1.151	0.953	0.290	0.117	0.104	0.095
14	0.138	0.251	0.198*	0.171*	0.336	0.692	1.046	0.880	0.281	0.105	0.218	0.114
15	0.131	0.234	0.196*	0.175	0.308	0.673	0.978	0.806	0.269	0.099	0.222	0.143
16	0.129	0.214	0.194*	0.181*	0.286	0.681	0.903	0.735	0.257	0.097	0.141	0.134
17	0.127	0.203	0.192*	0.172*	0.274	0.672	0.842	0.703	0.242	0.095	0.148	0.118
18	0.127	0.208	0.191*	0.171*	0.304	0.638	0.809	0.688	0.229	0.089	0.193	0.128
19	0.126	0.200	0.190*	0.171*	1.124	0.622	0.782	0.674	0.222	0.085	0.191	0.129
20	0.127	0.191	0.188*	0.171*	3.160	0.630	0.730	0.755	0.238	0.088	0.218	0.152
21	0.140	0.186	0.186*	0.172*	1.792	0.659	0.702	0.699	0.218	0.084	0.343	0.186
22	0.158	0.182	0.155	0.176*	1.243	0.717	0.683	0.648	0.236	0.083	0.273	0.178
23	0.164	0.176	0.141	0.189*	1.214	0.810	0.685	0.607	0.239	0.080	0.229	0.166
24	0.155	0.182	0.145	0.210*	1.328	0.889	0.710	0.574	0.210	0.077	0.173	0.148
25	0.148	0.174*	0.200	0.230*	1.212	0.883	0.727	0.675	0.198	0.074	0.142	0.132
26	0.142	0.171*	0.274	0.227	1.136	0.839	0.716	0.685	0.189	0.074	0.131	0.125
27	0.169	0.186	0.263	0.213	1.092	0.781	0.710	0.610	0.179	0.072	0.128	0.121
28	0.616	0.179*	0.246	0.204	1.167	0.790	0.776	0.552	0.176	0.070	0.123	0.118*
29	0.325	0.171*	0.240	0.197	1.325	0.926	0.964	0.516	0.187	0.069	0.117	0.117
30	0.249	0.169*	0.235	0.191		1.083	1.165	0.486	0.188	0.064	0.112	0.117
31	0.212		0.226	0.186		1.107		0.457		0.067	0.107	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	5.560	5.823	5.912	5.839	20.999	29.188	29.035	23.619	8.590	3.180	4.132	3.576
TOTAL FLOW (cms days)	0.157	0.165	0.167	0.165	0.595	0.827	0.822	0.669	0.243	0.090	0.117	0.101
TOTAL DEPTH (in)	0.455	0.476	0.484	0.478	1.718	2.387	2.375	1.932	0.703	0.260	0.338	0.292
TOTAL DEPTH (cm)	1.155	1.210	1.228	1.213	4.363	6.064	6.032	4.907	1.785	0.661	0.858	0.743

ANNUAL SUMMARY:
Sum of Mean Daily Flow 145.454 cfs = 4.119 cms
Total Depth 11.897 in = 30.218 cm
Maximum Instantaneous Flow 4.454 cfs = 0.126 cms on February 20 at 02.90 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 2
WATERSHED AREA: 291 ACRES (117 HECTARES)

WATER YEAR 1969
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.118	0.142	0.237	0.206	0.370	0.283	3.103	2.017	0.640	0.288	0.101	0.054
2	0.116	0.121	0.226	0.204	0.362	0.291	3.574	1.935	0.602	0.266	0.099	0.050
3	0.116	0.134	0.222	0.201	0.355	0.318	3.502	1.950	0.565	0.254	0.098	0.051
4	0.116	0.145	0.223	0.199*	0.351	0.325	3.345	2.240	0.526	0.243	0.090	0.051
5	0.117	0.145	0.225	0.221*	0.347	0.354	4.145	2.641	0.505	0.235	0.095	0.056
6	0.119	0.143	0.212	0.288*	0.343	0.355	4.772	2.968	0.476	0.248	0.092	0.053
7	0.120	0.139	0.218	0.362	0.338	0.343	3.462	3.292	0.451	0.241	0.089	0.051
8	0.122	0.139	0.218	0.330	0.333	0.333	2.780	3.400	0.468	0.223	0.089	0.042
9	0.123	0.253	0.217	0.311	0.326	0.326	3.322	3.351	0.466	0.210	0.089	0.041
10	0.125	0.246	0.233	0.303	0.314	0.319	3.662	3.262	0.434	0.199	0.085	0.044
11	0.140	0.272	0.253	0.297	0.302	0.322	3.582	3.071	0.406*	0.189	0.097	0.046
12	0.184	0.634	0.233	0.289	0.302	0.328*	3.833	2.808	0.404*	0.185	0.093	0.050
13	0.205	0.456	0.233	0.328*	0.302	0.362*	3.883	2.637	0.349	0.177	0.087	0.051
14	0.191	0.340	0.234	0.345	0.295	0.422*	3.596	2.942	0.330	0.174	0.082	0.050
15	0.193	0.291	0.233	0.332	0.292	0.482*	3.309	2.451	0.322	0.170	0.083	0.050
16	0.190	0.252	0.231	0.318	0.290	0.556	3.364	2.103	0.314	0.163	0.078	0.049
17	0.182	0.233	0.221	0.309	0.289	0.559	3.516	1.908	0.296	0.155	0.080	0.046
18	0.175	0.263	0.220	0.303	0.289	0.581	4.114	1.827	0.290	0.150	0.077	0.045
19	0.169	0.303	0.220	0.297	0.285	0.537	3.314	1.738	0.292	0.148	0.076	0.082
20	0.179	0.285	0.217	0.298	0.285	0.509	2.967	1.733	0.299	0.141	0.072	0.129
21	0.177	0.271	0.217	0.762	0.291	0.588	3.546	1.541	0.288	0.149	0.063	0.088
22	0.172	0.510	0.217	0.654	0.294	0.744	4.687*	1.395	0.278	0.138	0.057	0.077
23	0.170	0.500	0.217	0.539	0.292	0.771	5.050*	1.287	0.323	0.135	0.055	0.086
24	0.167	0.395	0.217	0.494	0.291	0.728	4.426	1.188	0.668	0.131	0.051	0.089
25	0.162	0.337	0.217	0.473	0.290	0.874	3.204	1.088	0.496	0.128	0.043	0.077
26	0.156	0.298	0.215	0.462	0.288	1.275	2.679	0.982	0.427	0.121	0.048	0.076
27	0.150	0.282	0.213	0.436	0.285	1.420	2.541	0.918	0.392	0.119	0.049	0.085
28	0.148	0.263	0.212*	0.414	0.283	1.446	2.547	0.847	0.374	0.116	0.051	0.083
29	0.147	0.254	0.206	0.397		1.961	2.554	0.768	0.353	0.112	0.052	0.085
30	0.163	0.247	0.206	0.387		2.731	2.238	0.770	0.319	0.110	0.054	0.097
31	0.155		0.206	0.376		3.245		0.699		0.105	0.054	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	4.766	8.293	6.866	11.134	8.684	23.689	104.616	61.756	12.354	5.425	2.328	1.934
TOTAL FLOW (cms days)	0.135	0.235	0.194	0.315	0.246	0.671	2.963	1.749	0.350	0.154	0.066	0.055
TOTAL DEPTH (in)	0.390	0.678	0.562	0.911	0.710	1.938	8.557	5.051	1.010	0.444	0.190	0.158
TOTAL DEPTH (cm)	0.990	1.723	1.426	2.313	1.804	4.921	21.734	12.830	2.567	1.127	0.484	0.402

ANNUAL SUMMARY:
Sum of Mean Daily Flow 251.844 cfs = 7.132 cms
Total Depth 20.599 in = 52.321 cm
Maximum Instantaneous Flow 5.575 cfs = 0.158 cms on April 23 at 19.25 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 2
WATERSHED AREA: 291 ACRES (117 HECTARES)

WATER YEAR 1970
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.100	0.156	0.155	0.207	0.224	0.741	0.766	0.921	1.586	0.682	0.146	0.097
2	0.156	0.152	0.155	0.211	0.206	0.685	0.726	1.494	1.545	0.572	0.141	0.094
3	0.130	0.151	0.155	0.215	0.193	0.594	0.711	2.470	1.474	0.499	0.138	0.095
4	0.124	0.149	0.155	0.220	0.179	0.515	0.785	3.705	1.368	0.457	0.132	0.160
5	0.116	0.169	0.155	0.223	0.170	0.447	1.220	4.801*	1.242	0.412	0.153	0.164
6	0.115	0.203	0.155	0.228	0.161	0.413	2.142	4.879*	1.137	0.379	0.141	0.147
7	0.117	0.182	0.155	0.234	0.161	0.416	2.174	4.289	1.057	0.350	0.131	0.157
8	0.160	0.171	0.155	0.237	0.242	0.559	1.749	3.396	0.970	0.322	0.129	0.245
9	0.178	0.166	0.160	0.237	0.354	0.580	1.776	3.617	1.054	0.304	0.127	0.134
10	0.166	0.163	0.162	0.236	0.454	0.627	2.611	3.134	0.956	0.350	0.124	0.120
11	0.142	0.162	0.167*	0.235	0.505	0.648	2.223	2.586	0.833*	0.314	0.125	0.117
12	0.140	0.160	0.173*	0.234	0.754	0.584	1.717	2.219	0.766*	0.282	0.120	0.120
13	0.140	0.156	0.188	0.232	0.754	0.536	1.488	1.906	0.829*	0.258	0.116	0.121
14	0.140	0.154	0.185	0.217	0.570	0.619	1.283	1.742	0.951*	0.266*	0.117	0.125
15	0.141	0.153	0.178	0.205	0.441	0.801	1.139	2.024	0.965*	0.254	0.113	0.128*
16	0.141	0.152	0.171	0.185	0.380	0.805	1.070	3.236	0.823*	0.243	0.110	0.128*
17	0.141	0.148	0.169	0.138	0.397	0.720	1.126	4.402*	0.735*	0.239	0.106	0.152
18	0.143	0.144	0.169	0.124	0.352	0.646	1.219	4.748*	0.691*	0.218	0.103	0.162*
19	0.143	0.146	0.172	0.139	0.324	0.597	1.216	4.066	0.650*	0.208	0.100	0.217
20	0.143	0.147	0.184	0.190	0.312	0.610	1.122	3.681	0.614*	0.201	0.100	0.209
21	0.143	0.147	0.395	0.256	0.346	0.694	1.039	3.459	0.577*	0.199	0.101	0.188
22	0.143	0.145	0.380	0.412	0.461	0.788	0.987	3.278	0.538*	0.192	0.099	0.174
23	0.143	0.150	0.251	0.869	0.575	0.854	0.953	3.624	0.503*	0.191	0.092	0.171
24	0.143	0.154	0.207	1.729	0.662	0.906	0.910	3.162	0.471*	0.188	0.090	0.163
25	0.143	0.151	0.199	0.806	0.736	0.893	0.858	3.081	0.440*	0.181	0.089	0.164
26	0.143	0.151	0.184	0.509	0.795	0.902	0.810	2.944	0.382*	0.177	0.089	0.163
27	0.148	0.154	0.179*	0.385	0.849	0.939	0.776	2.709	0.571	0.167	0.089	0.158
28	0.174	0.155	0.184	0.313	0.833	0.964	0.760	2.302	0.676	0.176	0.089	0.153
29	0.160	0.155	0.191	0.276		0.857	0.737	2.045	1.095	0.163	0.090	0.151
30	0.158	0.155	0.197	0.254		0.773	0.744	1.820	0.894	0.158	0.093	0.150
31	0.159		0.203	0.241		0.756		1.664		0.152	0.097	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	4.438	4.700	5.888	10.196	12.388	21.468	36.837	93.404	26.395	8.754	3.491	4.526
TOTAL FLOW (cms days)	0.126	0.133	0.167	0.289	0.351	0.608	1.043	2.645	0.748	0.248	0.099	0.128
TOTAL DEPTH (in)	0.363	0.384	0.482	0.834	1.013	1.756	3.013	7.640	2.159	0.716	0.286	0.370
TOTAL DEPTH (cm)	0.922	0.976	1.223	2.118	2.574	4.460	7.653	19.405	5.484	1.819	0.725	0.940

ANNUAL SUMMARY:
Sum of Mean Daily Flow 232.486 cfs = 6.584 cms
Total Depth 19.016 in = 48.300 cm
Maximum Instantaneous Flow 5.869 cfs = 0.166 cms on May 5 at 19.50 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 2
WATERSHED AREA: 291 ACRES (117 HECTARES)

WATER YEAR 1971
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.150	0.280	0.383	0.463	1.165	0.451*	1.192*	6.426*	1.763*	0.705	0.199	0.135
2	0.153	0.286	0.370	0.463	1.165	0.534*	1.218*	7.364*	1.685*	0.645	0.216	0.154
3	0.154	0.267	0.358	0.459	0.958	0.631*	1.328*	8.432*	1.609*	0.590	0.206	0.151
4	0.153	0.253	0.383	0.459	0.839	0.617*	1.514*	9.492*	1.538*	0.545	0.190	0.149
5	0.158	0.309	0.353	0.454	0.751	0.591*	1.826*	10.458*	1.469*	0.508	0.186	0.138
6	0.166*	0.409	0.392	0.444	0.689	0.564*	2.357*	10.124*	1.404*	0.482	0.190	0.148
7	0.168	0.438	0.425	0.436	0.646	0.539*	3.176*	8.717*	1.341*	0.445	0.184	0.175
8	0.165	0.392	0.441	0.436	0.620	0.514*	3.569*	7.524*	1.281*	0.412	0.176	0.147
9	0.187	0.566	0.423	0.442	0.588	0.492*	3.391*	6.497*	1.225*	0.389	0.167	0.139
10	0.201	0.630	0.401	0.453	0.617	0.470*	3.333*	5.612*	1.171*	0.366	0.160	0.131
11	0.181	0.478	0.387	0.461	0.604	0.448*	3.195*	4.846*	1.118*	0.351	0.157	0.129
12	0.177	0.412	0.385	0.470	0.640	0.428*	2.929*	4.391*	0.952	0.328	0.156	0.130
13	0.177	0.366	0.405	0.467	0.717	0.410*	2.865*	4.197*	0.891	0.318	0.154	0.124
14	0.178	0.339	0.407	0.477	0.767	0.391*	3.251*	4.010*	0.824	0.303	0.159	0.125
15	0.177	0.318	0.408	0.478	0.782	0.374*	3.973*	3.829*	0.767	0.291	0.151	0.128
16	0.176	0.307	0.408	0.489	0.792	0.357*	4.329*	3.658*	0.723	0.279	0.148	0.130
17	0.174	0.290	0.403	0.505	0.759	0.342*	4.315*	3.497*	0.681	0.267	0.146	0.136
18	0.175	0.283	0.407	0.530	0.713	0.326*	4.253*	3.341*	0.679	0.259	0.141	0.142
19	0.181	0.271	0.412	0.553	0.672	0.311*	4.430*	3.192*	0.658	0.287	0.140	0.142
20	0.181	0.267	0.411	0.567	0.630	0.298*	5.103*	3.050*	0.600	0.275	0.137	0.140
21	0.186	0.249	0.408	0.580	0.605	0.284*	5.850*	2.912*	0.572	0.252	0.137	0.142
22	0.196	0.264	0.411	0.583	0.606	0.271*	5.759*	2.781*	0.544	0.240	0.135	0.139
23	0.203	0.339	0.415	0.576	0.588*	0.260*	4.975*	2.657*	0.517	0.253	0.140	0.139
24	0.205	3.453	0.410	0.603	0.566*	0.434*	4.509*	2.539*	0.498	0.266	0.138	0.137
25	0.201	2.221	0.411	0.613	0.541*	0.686*	4.307*	2.427*	0.619	0.260	0.139	0.147
26	0.203	0.991	0.412	0.600	0.517*	0.809*	4.117*	2.319*	1.164	0.250	0.129	0.160
27	0.205	0.674	0.407	0.595	0.493*	0.887*	4.511*	2.215*	1.315	0.242	0.126	0.165
28	0.219	0.540	0.413	0.588	0.471*	0.877*	5.199*	2.116*	1.186	0.231	0.123	0.163
29	0.244	0.464	0.424	0.594		0.882*	5.590*	2.021*	0.980	0.223	0.132	0.181
30	0.264	0.435	0.434	0.594		1.029*	5.909*	1.932*	0.804	0.219	0.135	0.176
31	0.275		0.455	0.812		1.176*		1.846*		0.209	0.138	
MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	5.832	16.791	12.564	16.245	19.501	16.684	112.274	144.425	30.575	10.689	4.834	4.340
TOTAL FLOW (cms days)	0.165	0.476	0.356	0.460	0.552	0.472	3.180	4.090	0.866	0.303	0.137	0.123
TOTAL DEPTH (in)	0.477	1.373	1.028	1.329	1.595	1.365	9.183	11.813	2.501	0.874	0.395	0.355
TOTAL DEPTH (cm)	1.212	3.488	2.610	3.375	4.051	3.466	23.325	30.005	6.352	2.221	1.004	0.902

ANNUAL SUMMARY:
Sum of Mean Daily Flow 394.755 cfs = 11.179 cms
Total Depth 32.288 in = 82.012 cm
Maximum Instantaneous Flow 10.896 cfs = 0.309 cms on May 5 at 24.00 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 2
WATERSHED AREA: 291 ACRES (117 HECTARES)

WATER YEAR 1972
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.176	0.178	0.176	0.170	0.161	0.775	1.253	2.793	1.706*	0.397	0.143	0.109
2	0.164	0.175	0.205	0.171	0.161	0.592	1.685	2.931	1.479*	0.381	0.140	0.107
3	0.155	0.173	0.175	0.165	0.161	0.664	2.023	3.747	1.281*	0.341	0.138	0.105
4	0.144	0.172	0.170	0.164	0.162	0.537	1.994	4.754	1.126*	0.287	0.135	0.105
5	0.136	0.171	0.174*	0.165	0.163	0.479	2.460	4.881*	0.996*	0.230	0.128	0.146
6	0.135	0.174*	0.183	0.165	0.163	0.456	3.264	4.894*	0.910*	0.199	0.124	0.154
7	0.138	0.178	0.179	0.164	0.163	0.470	2.942	4.605	0.927*	0.215	0.121	0.134
8	0.135	0.178	0.183	0.161	0.161	0.499	2.426	4.475	1.147*	0.176	0.118	0.129*
9	0.134	0.176	0.186	0.158	0.160	0.892	2.310	3.563	1.599*	0.188	0.119	0.124
10	0.135	0.181	0.187	0.156	0.159	1.907	2.222	3.322	1.964*	0.197	0.119	0.130*
11	0.135	0.204	0.187	0.161	0.159	2.338	2.002	3.518	1.853*	0.205*	0.116	0.138
12	0.135	0.224	0.187	0.159	0.159	1.943	1.871	3.730	1.492*	0.235*	0.113	0.147
13	0.137	0.203	0.187	0.157	0.159	2.236	1.667	4.155	1.215*	0.225*	0.119	0.146
14	0.140	0.191	0.187	0.157	0.159	2.332	1.495	4.508*	1.036*	0.218*	0.141	0.133
15	0.145	0.183	0.186	0.157	0.158	2.393	1.422	4.728	0.906*	0.213*	0.167	0.127
16	0.148	0.175	0.185	0.157	0.157	2.841	1.456	4.449	0.820*	0.209*	0.148	0.122
17	0.148	0.175	0.184	0.157	0.161	3.708	1.371	4.214	0.765*	0.203*	0.130	0.119
18	0.150	0.170	0.179	0.157	0.175	3.586	1.289	3.557	0.715*	0.184	0.122	0.119
19	0.161	0.169	0.177	0.158	0.204	2.719	1.373	3.286	0.673*	0.192	0.119	0.141
20	0.216	0.173	0.176	0.167	0.252	2.199	1.634	3.166	0.631*	0.200	0.119	0.135
21	0.182	0.175	0.176	0.205	0.296	2.282	1.838	2.824	0.598*	0.203	0.116	0.128
22	0.171	0.174	0.191	0.191	0.305	3.153	1.894	2.600	0.562	0.195	0.112	0.135*
23	0.165	0.169	0.200	0.169	0.276	3.437	2.307	2.418	0.557	0.188	0.114	0.134*
24	0.163	0.175	0.185	0.158	0.253	2.286	2.613	2.297	0.546	0.176	0.112	0.142
25	0.161	0.175	0.183	0.156	0.237	1.737	2.284	2.163	0.637	0.172	0.108	0.148
26	0.169	0.178*	0.183	0.154	0.235	1.421	2.152	2.095	0.564	0.167	0.104	0.145
27	0.171	0.187	0.181	0.153	0.379	1.202	2.804	2.088	0.504	0.163	0.102	0.162
28	0.163	0.180	0.177	0.151	1.296	1.051	4.020	2.095*	0.472	0.169	0.131*	0.151
29	0.180	0.180	0.177	0.148	1.343	0.922	3.872	2.041*	0.443	0.153	0.130	0.151
30	0.171	0.177	0.176	0.154		0.861	3.092	1.993*	0.428	0.155	0.117	0.149
31	0.174		0.174	0.161		1.045		1.888*		0.149	0.112	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	4.836	5.390	5.652	5.023	7.974	52.963	65.036	103.780	28.550	6.585	3.836	4.015
TOTAL FLOW (cms days)	0.137	0.153	0.160	0.142	0.226	1.500	1.842	2.939	0.809	0.186	0.109	0.114
TOTAL DEPTH (in)	0.396	0.441	0.462	0.411	0.652	4.332	5.319	8.488	2.335	0.539	0.314	0.328
TOTAL DEPTH (cm)	1.005	1.120	1.174	1.044	1.657	11.003	13.511	21.561	5.931	1.368	0.797	0.834

ANNUAL SUMMARY:
Sum of Mean Daily Flow 293.640 cfs = 8.316 cms
Total Depth 24.018 in = 61.005 cm
Maximum Instantaneous Flow 6.176 cfs = 0.175 cms on May 4 at 17.75 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 2
WATERSHED AREA: 291 ACRES (117 HECTARES)

WATER YEAR 1973
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.149	0.155*	0.172	0.237	0.275	0.535	0.588	0.982	0.334	0.147	0.069	0.078
2	0.143	0.165*	0.171	0.236	0.271	0.520	0.552	0.952	0.317	0.140	0.070	0.071
3	0.140	0.173*	0.170	0.229	0.269	0.489	0.601	1.041	0.306	0.135	0.081	0.065
4	0.140	0.205*	0.182	0.230	0.266	0.454	0.827	1.204	0.292	0.130	0.077	0.061
5	0.140	0.241*	0.203	0.227	0.260	0.455	1.035	1.124	0.275	0.128	0.072	0.060
6	0.145	0.221*	0.204	0.225	0.254	0.445	1.025	1.096	0.251	0.124	0.072	0.061
7	0.146	0.194*	0.204	0.225	0.251	0.446	0.874	1.059	0.248	0.121	0.071	0.152
8	0.143	0.194*	0.204	0.225	0.249	0.439	0.819	1.129	0.238	0.117	0.065	0.096
9	0.151	0.193*	0.205	0.225	0.249	0.457	0.803	0.999	0.229	0.113	0.064	0.079
10	0.215	0.187*	0.209	0.224	0.250	0.443	0.841	0.883	0.222	0.108	0.069	0.076
11	0.219	0.185*	0.212	0.222*	0.249	0.414	1.032	0.794	0.212	0.106	0.067	0.073
12	0.171	0.182*	0.212	0.230*	0.240	0.406	1.262	0.773	0.205	0.107	0.062	0.073
13	0.159	0.178*	0.212	0.349*	0.225	0.409	1.790	0.799	0.202	0.104	0.059	0.072
14	0.160	0.176*	0.211	0.536	0.220	0.398	1.682	0.815	0.277	0.104	0.058	0.084
15	0.169	0.169	0.210	0.478	0.218	0.409	1.366	0.796	0.260	0.100	0.057	0.087
16	0.162	0.165	0.211	0.661	0.217	0.451	1.206	0.774	0.237	0.096	0.057	0.085
17	0.153	0.177	0.214	0.590	0.218	0.512	1.144	0.727	0.302	0.090	0.056	0.085
18	0.148	0.175	0.217	0.450	0.219	0.486	1.003	0.680	0.256	0.089	0.058	0.082
19	0.152	0.173	0.221*	0.380	0.219	0.461	0.877	0.625	0.227	0.098	0.059	0.118
20	0.151	0.169	0.195	0.351	0.221	0.463	0.797	0.576	0.204	0.107	0.058	0.220
21	0.146	0.165	0.347	0.341	0.237	0.456	0.774	0.519	0.192	0.109	0.067	0.132
22	0.147	0.175	1.017*	0.328	0.264	0.449	0.833	0.475	0.176	0.102	0.067	0.115
23	0.146	0.173	0.451	0.325	0.286	0.472	1.043	0.436	0.177	0.096	0.063	0.128
24	0.148*	0.171	0.363	0.318	0.323	0.644	1.201	0.455*	0.175	0.096	0.062	0.213
25	0.149*	0.172	0.310	0.311	0.315	0.945	1.245	0.549*	0.171	0.085	0.076	0.210
26	0.148*	0.208	0.289	0.299	0.321	1.005	1.357	0.507	0.166	0.083	0.069	0.153
27	0.148*	0.176	0.272	0.289	0.405	0.813	1.546	0.440	0.158	0.081	0.065	0.133
28	0.150*	0.194	0.258	0.288	0.477	0.696	1.419	0.410	0.152	0.078	0.061	0.122
29	0.151*	0.203	0.245	0.288		0.646	1.169	0.379	0.156	0.075	0.061	0.115
30	0.151*	0.191	0.243	0.284		0.637	1.034	0.358	0.148	0.075	0.057	0.111
31	0.151*		0.242	0.279		0.626		0.352		0.071	0.076	

MONTHLY SUMMARY:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	4.792	5.503	8.075	9.879	7.462	16.481	31.744	22.707	6.764	3.213	2.025	3.211
TOTAL FLOW (cms days)	0.136	0.156	0.229	0.280	0.211	0.467	0.899	0.643	0.192	0.091	0.057	0.091
TOTAL DEPTH (in)	0.392	0.450	0.660	0.808	0.610	1.348	2.596	1.857	0.553	0.263	0.166	0.263
TOTAL DEPTH (cm)	0.996	1.143	1.678	2.052	1.550	3.424	6.595	4.717	1.405	0.667	0.421	0.667

ANNUAL SUMMARY:
Sum of Mean Daily Flow 121.855 cfs = 3.451 cms
Total Depth 9.967 in = 25.316 cm
Maximum Instantaneous Flow 2.064 cfs = 0.058 cms on December 22 at 08.08 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 2
WATERSHED AREA: 291 ACRES (117 HECTARES)

WATER YEAR 1974
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.112	0.395*	0.420	0.328	0.463	0.447	1.939	5.393	2.158	0.380	0.180	0.113
2	0.113	0.324*	0.416	0.330*	0.442	0.446	1.690	5.420*	2.095	0.374	0.186	0.115
3	0.115	0.207*	0.393	0.335*	0.430	0.415	1.497	5.495	2.030	0.365	0.199	0.115
4	0.113*	0.166*	0.379	0.343*	0.425	0.406	1.345	5.798	2.017	0.342	0.192	0.112
5	0.108*	0.151*	0.368	0.346*	0.408	0.406	1.316	6.611	1.975	0.331	0.185	0.114
6	0.101*	0.236*	0.362	0.347*	0.399	0.401	1.542	6.434	1.747	0.332	0.200	0.112
7	0.168*	0.338*	0.379	0.348*	0.397	0.393	1.497	6.449*	1.583	0.333	0.216	0.109
8	0.219*	0.337*	0.378	0.350*	0.391	0.380	1.667	6.801*	1.433	0.333	0.179	0.106
9	0.179*	0.449*	0.372	0.351*	0.386	0.371	1.934	6.108	1.310	0.423	0.166	0.107
10	0.158*	1.004*	0.371	0.353*	0.389	0.391	1.789	4.876	1.234	0.449	0.156	0.111
11	0.147*	1.624*	0.368	0.355*	0.396	0.435	1.847	4.097	1.155	0.460	0.150	0.112
12	0.144*	2.179*	0.359	0.355*	0.403	0.508	1.934	3.774	1.066	0.384	0.147	0.122
13	0.142*	1.959*	0.357	0.371*	0.402	0.607	1.877	3.226	1.003	0.343	0.149	0.120
14	0.137*	0.930	0.351	0.568*	0.394	0.575	2.384	2.812	0.930	0.316	0.153	0.114
15	0.130*	0.726	0.345	1.488*	0.389	0.563	3.055	2.487	0.858	0.310	0.152	0.108
16	0.124*	0.633	0.390	3.135	0.386	0.742	3.872	2.274	0.794	0.302	0.145	0.103
17	0.117*	0.603	0.498	2.571	0.381	2.074	4.644	2.174	0.733	0.279	0.141	0.101
18	0.109*	0.556	0.461	1.472	0.378	1.920	5.750	2.045	0.673	0.260	0.135	0.098
19	0.103*	0.508	0.441	1.173	0.375	1.662	6.150	1.977	0.626	0.248	0.156	0.097
20	0.103*	0.469	0.428	1.004	0.357	1.362	5.609	1.963	0.666	0.236	0.211	0.096
21	0.114*	0.445	0.421	0.880	0.357	1.217	5.266*	1.937	0.613	0.228	0.170	0.099
22	0.119*	0.415	0.411	0.802	0.356	1.153	5.442*	2.004*	0.533	0.221	0.159	0.099
23	0.145*	0.393	0.398	0.724	0.352	1.052	7.291*	2.349	0.517	0.215	0.149	0.098
24	0.185*	0.377	0.381	0.675	0.352	1.134	8.210	2.687	0.512	0.208	0.147	0.097
25	0.230*	0.365	0.373	0.636	0.353	1.406	7.337	2.904	0.480	0.202	0.139	0.097
26	0.243*	0.352	0.371	0.590	0.354	2.003	5.834	3.430	0.464	0.199	0.133	0.092
27	0.207*	0.338	0.377	0.559	0.348	2.319	4.205	3.581	0.447	0.198	0.125	0.103
28	0.185*	0.334	0.377	0.534	0.357	2.596	3.381	3.188	0.433	0.201	0.120	0.103
29	0.176*	0.346	0.356	0.513		2.012	3.534	2.735	0.416	0.190	0.116	0.102
30	0.170*	0.367	0.340	0.495		2.233	4.692	2.427	0.400	0.189	0.114	0.101
31	0.267*		0.332	0.486		2.226		2.280		0.187	0.114	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	4.682	17.526	11.972	22.815	10.822	33.854	108.525	115.739	30.896	9.040	4.881	3.174
TOTAL FLOW (cms days)	0.133	0.496	0.339	0.646	0.306	0.959	3.073	3.278	0.875	0.256	0.138	0.090
TOTAL DEPTH (in)	0.383	1.433	0.979	1.866	0.885	2.769	8.877	9.467	2.527	0.739	0.399	0.260
TOTAL DEPTH (cm)	0.973	3.641	2.487	4.740	2.248	7.033	22.546	24.045	6.419	1.878	1.014	0.659

ANNUAL SUMMARY:
Sum of Mean Daily Flow 373.927 cfs = 10.590 cms
Total Depth 30.584 in = 77.684 cm
Maximum Instantaneous Flow 9.904 cfs = 0.280 cms on April 23 at 18.00 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 2
WATERSHED AREA: 291 ACRES (117 HECTARES)

WATER YEAR 1975
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.101	0.145	0.166	0.155*	0.207	0.262	0.276	0.836	2.690	0.457	0.150	0.148
2	0.107	0.144	0.164	0.155*	0.200	0.433	0.272	1.541	2.690	0.423	0.141	0.149
3	0.111	0.142	0.152	0.156*	0.194	0.396	0.270	2.391	2.411	0.394	0.134	0.145
4	0.112	0.142	0.176	0.158*	0.190	0.386	0.264	1.886	2.060	0.384	0.129	0.140
5	0.126	0.142	0.170	0.160	0.186	0.429	0.260	1.379	1.985	0.361	0.125	0.135
6	0.127	0.142	0.161	0.164	0.185	0.427	0.256	1.148	1.909	0.345	0.120	0.133
7	0.127	0.190	0.157	0.163	0.185	0.496	0.252	1.082	1.671	0.320	0.120	0.126
8	0.120	0.197	0.156	0.163	0.184	0.623	0.250	1.398	1.446	0.303	0.122	0.121
9	0.149	0.167	0.167	0.164	0.184	0.549	0.246	2.199	1.265*	0.287	0.119	0.119
10	0.140	0.164	0.152	0.166	0.187	0.427	0.242	3.993	1.142*	0.275	0.113	0.116
11	0.129	0.160	0.149	0.167	0.183	0.376	0.286	4.578	1.051	0.272	0.108	0.114
12	0.120	0.160	0.145	0.168	0.186	0.346	0.490	4.765	0.952	0.268	0.106	0.114
13	0.124	0.162	0.144	0.169	0.198	0.343	0.818	5.775	0.869	0.270	0.105	0.113
14	0.117	0.161	0.135	0.169	0.201	0.350	0.859*	7.386	0.787	0.247	0.106	0.160
15	0.113	0.161	0.128	0.170	0.194	0.385	0.682*	8.180	0.720	0.238	0.107	0.157
16	0.114	0.160	0.136	0.172	0.192	0.361	0.652*	6.706*	0.653	0.232	0.107	0.133
17	0.115	0.157	0.142	0.173	0.191	0.329	0.652*	5.784	0.841	0.238	0.116	0.124
18	0.112	0.177	0.147	0.193	0.190	0.367	0.751*	5.274	1.308	0.230	0.185	0.124
19	0.113	0.167	0.150	0.192	0.193	0.438	0.879*	4.374	1.135	0.210	0.209	0.122
20	0.117	0.165	0.152	0.192	0.194	0.378	0.958*	3.116	1.097	0.195	0.197	0.120
21	0.138	0.175	0.149	0.189	0.191	0.346	1.048*	2.850	0.923	0.185	0.168	0.116
22	0.132	0.180	0.146*	0.185	0.188	0.318	1.211*	2.625	0.807	0.179	0.216	0.113
23	0.140	0.164	0.147*	0.186	0.187	0.288	1.362*	2.549	0.719	0.168	0.278	0.111
24	0.165	0.164	0.148*	0.189	0.187	0.277	1.303*	2.306	0.681	0.161	0.245	0.110
25	0.166	0.161	0.151*	0.341	0.206	0.275*	1.216	1.980	0.700	0.154	0.195	0.108
26	0.159	0.152	0.152*	0.286	0.230	0.277	1.016	1.899	0.645	0.145	0.174	0.106
27	0.151	0.154	0.152*	0.235	0.231	0.276	0.883	2.050	0.592	0.142	0.156	0.110
28	0.152	0.157	0.154*	0.226	0.225	0.274	0.802	2.268	0.557	0.139	0.181	0.111
29	0.153	0.170	0.155*	0.209		0.277	0.745	2.398	0.528	0.146	0.174	0.110
30	0.146	0.174	0.156*	0.205		0.285	0.731	2.605	0.488	0.178	0.156	0.110
31	0.145		0.156*	0.207		0.282		2.726		0.158	0.148	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	4.043	4.853	4.715	5.823	5.469	11.273	19.931	100.046	35.325	7.703	4.710	3.717
TOTAL FLOW (cms days)	0.114	0.137	0.134	0.165	0.155	0.319	0.564	2.833	1.000	0.218	0.133	0.105
TOTAL DEPTH (in)	0.331	0.397	0.386	0.476	0.447	0.922	1.630	8.183	2.889	0.630	0.385	0.304
TOTAL DEPTH (cm)	0.840	1.008	0.979	1.210	1.136	2.342	4.141	20.785	7.339	1.600	0.979	0.772

ANNUAL SUMMARY:
Sum of Mean Daily Flow 207.608 cfs = 5.879 cms
Total Depth 16.981 in = 43.131 cm
Maximum Instantaneous Flow 10.255 cfs = 0.290 cms on May 14 at 16.75 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 2
WATERSHED AREA: 291 ACRES (117 HECTARES)

WATER YEAR 1976
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.105	0.301	0.967	0.241	0.343	0.294	0.933	3.562	0.801	0.260	0.174	0.118
2	0.107	0.289	0.699	0.242	0.367	0.287	0.787	4.101	0.729	0.250	0.161	0.114
3	0.107	0.306	0.530	0.243	0.374	0.285	1.000	4.259	0.691	0.239	0.148	0.112
4	0.110	0.305	0.553	0.242	0.362	0.284	1.799	4.285	0.644	0.233	0.156	0.114
5	0.110	0.292	0.764	0.243*	0.336	0.282	2.727	3.812	0.595	0.225	0.148	0.108
6	0.180	0.291	0.562	0.241*	0.307	0.281	2.633	3.700	0.560	0.210	0.130	0.129
7	0.303	0.333	0.967	0.247*	0.284	0.282	2.424	4.076	0.535	0.207	0.134	0.116
8	0.184	0.302	1.175	0.247*	0.272	0.289	3.353	4.289	0.513	0.203	0.164	0.111
9	0.164	0.274	1.064	0.244*	0.267	0.329	3.451	4.380	0.492	0.199	0.152	0.110
10	0.152	0.267	0.845	0.242*	0.257	0.429	3.186	4.382	0.511	0.193	0.135	0.112
11	0.227	0.248	0.657	0.238*	0.250	0.534	3.441	3.950	0.638	0.190	0.136	0.174
12	0.290	0.248	0.548	0.234*	0.244	0.469	3.245	3.169	0.569	0.196	0.128	0.158
13	0.253	0.249	0.494	0.231	0.241	0.438	2.745	3.207	0.569	0.190	0.122	0.139
14	0.215	0.253	0.454	0.229	0.246	0.420	2.725	3.183	0.487	0.182	0.128	0.139
15	0.198	0.302	0.442	0.225	0.248	0.410	2.597	2.693	0.438	0.175	0.215	0.137
16	0.190	0.387	0.388	0.223	0.250	0.407	2.184	2.459	0.457	0.165	0.199	0.162
17	0.181	0.358	0.354	0.222	0.249	0.415	1.960	2.312	0.433	0.193	0.171	0.175
18	0.173	0.324	0.349	0.237	0.248	0.441	1.815	2.096	0.406	0.351	0.180	0.180
19	0.170	0.324	0.344	0.241	0.247	0.452	1.701	1.911	0.382	0.234	0.164	0.170
20	0.170	0.313	0.338	0.238	0.243	0.435	1.714	1.722	0.369	0.206	0.149	0.152
21	0.242	0.295	0.334	0.234	0.240	0.418	1.723	1.571	0.414	0.185	0.138	0.142
22	0.241	0.308	0.329	0.232	0.239	0.421	1.774	1.448	0.392	0.174	0.158	0.150
23	0.216	0.280	0.312	0.234	0.241	0.421	1.719	1.331	0.362	0.191	0.189	0.157
24	0.201	0.247	0.287	0.234	0.267	0.420	2.057	1.232	0.357	0.189	0.164	0.147
25	0.204	0.234	0.280	0.231	0.275	0.415	2.575	1.135	0.342	0.172	0.156	0.143
26	0.246	0.233	0.276	0.226	0.287	0.400	2.120	1.047	0.334	0.157	0.167	0.138
27	0.239	0.232	0.271	0.222	0.304	0.387	1.918	0.993	0.321	0.151	0.150	0.139
28	0.232	0.227	0.257	0.223	0.299	0.375	1.866	0.988	0.298	0.144	0.140	0.141
29	0.241	0.212	0.258	0.243	0.296	0.365	2.142	0.891	0.279	0.162	0.132	0.142
30	0.310	0.205	0.257	0.274		0.396	2.735	0.838	0.261	0.154	0.126	0.143
31	0.317		0.246	0.310		0.592		0.937		0.151	0.122	

MONTHLY SUMMARY:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	6.273	8.440	15.600	7.412	8.079	12.072	67.052	79.961	14.177	6.130	4.738	4.170
TOTAL FLOW (cms days)	0.178	0.239	0.442	0.210	0.229	0.342	1.899	2.264	0.401	0.174	0.134	0.118
TOTAL DEPTH (in)	0.513	0.690	1.276	0.606	0.661	0.987	5.484	6.540	1.160	0.501	0.388	0.341
TOTAL DEPTH (cm)	1.303	1.753	3.241	1.540	1.678	2.508	13.930	16.612	2.945	1.273	0.984	0.866

ANNUAL SUMMARY:

Sum of Mean Daily Flow 234.104 cfs = 6.630 cms
Total Depth 19.148 in = 48.636 cm
Maximum Instantaneous Flow 5.136 cfs = 0.145 cms on May 9 at 18.00 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 2
WATERSHED AREA: 291 ACRES (117 HECTARES)

WATER YEAR 1977
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.142	0.146	0.153*	0.153*	0.151*	0.151*	0.188	0.203	0.212	0.095	0.062	0.071
2	0.152	0.143	0.151*	0.151*	0.151*	0.151*	0.186	0.210	0.198	0.107	0.062	0.064
3	0.156	0.140	0.153*	0.152*	0.151*	0.150*	0.191	0.208	0.183	0.113	0.066	0.060
4	0.154	0.139	0.153*	0.150*	0.152*	0.150*	0.293	0.201	0.176	0.115	0.060	0.059
5	0.153	0.137	0.149*	0.151*	0.151*	0.151*	0.477	0.193	0.163	0.102	0.053	0.057
6	0.151	0.136	0.150*	0.150*	0.150*	0.151*	0.581	0.195	0.150	0.100	0.052	0.056
7	0.150	0.136	0.151*	0.150*	0.149*	0.151*	0.680	0.194	0.338	0.099	0.056	0.054
8	0.150	0.136	0.152*	0.149*	0.149*	0.151*	0.693	0.186	0.336	0.095	0.081	0.054
9	0.153	0.135	0.153*	0.149*	0.149*	0.151*	0.558	0.169	0.248	0.093	0.057	0.058
10	0.152	0.135	0.153*	0.150*	0.149*	0.152*	0.445	0.240	0.412	0.095	0.052	0.056
11	0.154	0.137	0.153*	0.150*	0.149*	0.152*	0.388	0.210	0.461	0.092	0.049	0.055
12	0.149	0.138	0.153*	0.151*	0.149*	0.153*	0.384	0.195	0.375	0.092	0.046	0.058
13	0.142	0.136	0.151*	0.152*	0.149*	0.151*	0.389	0.176	0.298	0.090	0.044	0.059
14	0.142	0.136	0.151*	0.153*	0.150*	0.149*	0.374	0.164	0.276	0.089	0.041	0.059
15	0.139	0.143	0.150*	0.153*	0.151*	0.149*	0.369	0.159	0.241	0.084	0.046	0.069
16	0.139	0.147	0.149*	0.152*	0.151*	0.149*	0.381	0.198	0.207	0.080	0.047	0.097
17	0.139	0.149	0.149*	0.151*	0.153*	0.147*	0.369	0.206	0.180	0.077	0.044	0.116
18	0.141	0.149	0.149*	0.151*	0.151*	0.149*	0.339	0.210	0.168	0.077	0.041	0.069
19	0.145	0.149*	0.151*	0.151*	0.153*	0.149*	0.319	0.207	0.162	0.078	0.038	0.086
20	0.148	0.148*	0.151*	0.151*	0.151*	0.148*	0.311	0.187	0.166	0.078	0.036	0.127
21	0.151	0.148*	0.152*	0.151*	0.152*	0.149*	0.319	0.176	0.149	0.079	0.045	0.106
22	0.148	0.147*	0.153*	0.151*	0.151*	0.169*	0.335	0.171	0.142	0.085	0.052	0.097
23	0.146	0.148*	0.152*	0.151*	0.149*	0.211*	0.350	0.341	0.138	0.087	0.047	0.091
24	0.148	0.148*	0.151*	0.152*	0.150*	0.217*	0.344	0.477	0.130	0.158	0.074	0.196
25	0.159	0.149*	0.151*	0.152*	0.150*	0.201*	0.320	0.490	0.121	0.108	0.084	0.114
26	0.148	0.148*	0.152*	0.152*	0.151*	0.202*	0.297	0.398	0.116	0.089	0.139	0.098
27	0.139	0.151*	0.151*	0.152*	0.151*	0.195*	0.276	0.406	0.111	0.079	0.092	0.081
28	0.140	0.151*	0.151*	0.151*	0.150*	0.185*	0.255	0.340	0.107	0.070	0.083	0.087
29	0.148	0.150*	0.151*	0.153*		0.182	0.233	0.292	0.101	0.065	0.080	0.229
30	0.150	0.150*	0.151*	0.152*		0.181	0.214	0.252	0.095	0.064	0.093	0.188
31	0.146		0.152*	0.151*		0.182		0.226		0.065	0.085	
MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	4.577	4.306	4.693	4.690	4.214	5.080	10.858	7.479	6.159	2.801	1.906	2.673
TOTAL FLOW (cms days)	0.130	0.122	0.133	0.133	0.119	0.144	0.307	0.212	0.174	0.079	0.054	0.076
TOTAL DEPTH (in)	0.374	0.352	0.384	0.384	0.345	0.415	0.888	0.612	0.504	0.229	0.156	0.219
TOTAL DEPTH (cm)	0.951	0.894	0.975	0.974	0.875	1.055	2.256	1.554	1.280	0.582	0.396	0.555

ANNUAL SUMMARY:
Sum of Mean Daily Flow 59.434 cfs = 1.683 cms
Total Depth 4.861 in = 12.348 cm
Maximum Instantaneous Flow 2.482 cfs = 0.070 cms on June 7 at 21.00 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 2
WATERSHED AREA: 291 ACRES (117 HECTARES)

WATER YEAR 1978
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.134	0.116	0.215	0.212	0.167	0.272	4.428	2.713	0.879	0.288	0.093	0.080
2	0.114	0.126	0.309	0.211	0.166	0.259	3.156	2.681	0.884	0.282	0.092	0.074
3	0.101	0.122	0.561	0.210	0.163	0.270	2.439	2.472	0.863	0.293	0.091	0.067
4	0.095	0.121	0.484	0.211	0.160	0.276	2.033	2.148	0.827	0.299	0.086	0.069
5	0.089	0.176	0.372	0.213	0.159	0.276	1.763	1.842	0.777	0.289	0.083	0.081
6	0.082	0.176	0.316	0.212	0.193	0.286	1.617	1.690	0.706	0.282	0.076	0.163
7	0.082	0.158	0.280	0.211	0.207	0.322	1.542	1.626	0.642	0.277	0.072	0.192
8	0.081	0.144	0.252	0.211	0.200	0.398	1.543	1.669	0.591	0.261	0.070	0.180
9	0.080	0.135	0.238	0.206	0.196	0.672	1.652	1.873	0.560	0.248	0.068	0.127
10	0.081	0.134	0.227	0.206	0.190	0.765	1.949	2.146	0.628	0.241	0.071	0.141
11	0.081	0.134	0.220	0.203	0.189	0.896	2.229	2.194	0.632	0.237	0.075	0.128
12	0.084	0.134	0.214	0.203	0.187	0.789	2.066	1.997	0.557	0.225	0.076	0.123
13	0.086	0.136	0.243	0.201	0.186	0.632	1.899	2.016	0.497	0.209	0.174	0.122
14	0.086	0.133	1.838	0.198	0.185	0.544	1.821	2.189	0.462	0.208	0.141	0.112
15	0.085	0.233	3.801	0.197	0.181	0.485	1.918	2.255	0.433	0.204	0.116	0.111
16	0.082	0.245	1.469	0.196	0.179	0.500	2.242	1.970	0.413	0.201	0.125	0.113
17	0.082	0.196	0.890	0.196	0.177	0.811	1.924	1.780	0.389	0.198	0.113	0.117
18	0.082	0.172	0.625	0.195	0.176	1.541	1.746	1.674	0.410	0.169	0.103	0.124
19	0.080	0.163	0.494	0.187	0.180	1.826	1.761	1.596	0.402	0.140	0.094	0.128
20	0.081	0.162	0.454	0.187	0.192	2.068	1.871	1.575	0.374	0.121	0.089	0.130
21	0.080	0.152	0.456	0.189	0.243	2.380	1.714	1.616	0.354	0.118	0.088	0.131
22	0.082	0.146	0.404	0.189	0.284	2.935	1.566	1.555	0.337	0.111	0.117	0.129
23	0.084	0.142	0.303	0.187	0.344	3.315	1.512	1.472	0.319	0.117	0.101	0.124
24	0.085	0.142	0.281	0.184	0.347	2.673	1.591	1.441	0.313	0.113	0.088	0.125
25	0.090	0.243	0.268	0.173	0.323	2.290	1.971	1.360	0.379	0.105	0.083	0.128
26	0.122	0.827	0.251	0.171	0.314	2.773	2.876	1.263	0.317	0.088	0.085	0.134
27	0.107	0.466	0.242	0.169	0.300	3.768	2.960	1.202	0.295	0.079	0.084	0.134
28	0.105	0.325	0.238	0.167	0.279	4.370	2.635	1.175	0.292	0.092	0.081	0.134
29	0.109	0.280	0.219	0.167		4.714	2.517	1.146	0.271	0.092	0.080	0.134
30	0.127	0.242	0.212	0.167		5.089	2.518	1.031	0.309	0.091	0.082	0.134
31	0.118		0.212	0.168		4.810		0.896		0.090	0.082	

MONTHLY SUMMARY:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	2.876	6.081	16.587	5.999	6.068	53.004	63.458	54.263	15.111	5.769	2.883	3.691
TOTAL FLOW (cms days)	0.081	0.172	0.470	0.170	0.172	1.501	1.797	1.537	0.428	0.163	0.082	0.105
TOTAL DEPTH (in)	0.235	0.497	1.357	0.491	0.496	4.335	5.190	4.438	1.236	0.472	0.236	0.302
TOTAL DEPTH (cm)	0.598	1.263	3.446	1.246	1.261	11.012	13.184	11.273	3.139	1.199	0.599	0.767

ANNUAL SUMMARY:
Sum of Mean Daily Flow 235.791 cfs = 6.678 cms
Total Depth 19.286 in = 48.986 cm
Maximum Instantaneous Flow 5.209 cfs = 0.148 cms on March 29 at 21.00 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 2
WATERSHED AREA: 291 ACRES (117 HECTARES)

WATER YEAR 1979
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.129	0.131	0.116	0.122*	0.121*	0.117*	0.421*	1.572	0.392*	0.105*	0.067	0.086
2	0.127	0.129	0.109	0.125*	0.121*	0.116*	0.393*	1.481	0.374*	0.105*	0.065	0.075
3	0.128	0.125	0.108	0.125*	0.121*	0.116*	0.384*	1.401*	0.356*	0.104*	0.064	0.071
4	0.126	0.124	0.223	0.125*	0.120*	0.116*	0.379*	1.309*	0.337*	0.104*	0.059	0.074
5	0.125	0.126	0.155	0.125*	0.119*	0.116*	0.398*	1.274*	0.327*	0.104*	0.059	0.070
6	0.127	0.130	0.140	0.125*	0.119*	0.115*	0.642*	1.239*	0.315*	0.104*	0.059	0.067
7	0.126	0.132	0.141	0.125*	0.119*	0.115*	0.911*	1.084*	0.308*	0.104*	0.058	0.063
8	0.128	0.150	0.140	0.125*	0.119*	0.114*	0.991*	0.986*	0.300*	0.104*	0.068	0.060
9	0.127	0.143	0.141	0.125*	0.119*	0.116*	1.230*	0.919*	0.288*	0.103*	0.074	0.062
10	0.125	0.125	0.141	0.125*	0.119*	0.118*	1.210*	0.953*	0.274*	0.102*	0.058	0.064
11	0.127	0.124	0.141	0.125*	0.119*	0.130*	0.883*	0.980*	0.258*	0.102*	0.050	0.064
12	0.127	0.130	0.141	0.124*	0.119*	0.154*	0.676*	0.984*	0.242*	0.102*	0.062	0.062
13	0.126	0.131	0.140	0.123*	0.119*	0.180*	0.551*	0.967*	0.231*	0.102*	0.129	0.061
14	0.126	0.129	0.141	0.123*	0.119*	0.205*	0.540*	0.974*	0.220*	0.102*	0.118	0.060
15	0.126	0.131	0.142	0.123*	0.119*	0.231*	0.716	1.013*	0.209*	0.102*	0.090	0.059
16	0.124	0.133	0.145	0.123*	0.118*	0.257*	1.046*	1.051*	0.200*	0.101*	0.070	0.058
17	0.126	0.135	0.146	0.123*	0.118*	0.286*	1.596*	0.959*	0.202*	0.100*	0.074	0.058
18	0.127	0.136	0.147	0.123*	0.118*	0.316*	1.271*	0.891*	0.209*	0.100*	0.089	0.056
19	0.128	0.139	0.146	0.123*	0.118*	0.346*	0.970*	0.824	0.208*	0.100*	0.090	0.056
20	0.130	0.139	0.146	0.123*	0.118*	0.376*	0.856*	0.774	0.197*	0.100*	0.071	0.055
21	0.128	0.137	0.144	0.123*	0.118*	0.406*	0.883*	0.720	0.175*	0.100*	0.074	0.057
22	0.127	0.139	0.141	0.123*	0.118*	0.421*	1.022*	0.671	0.173*	0.099*	0.068	0.058
23	0.129	0.135	0.137	0.122*	0.118*	0.402*	1.260*	0.626	0.150*	0.098*	0.098	0.059
24	0.129	0.133	0.120	0.121*	0.118*	0.429*	1.189*	0.680	0.143*	0.098*	0.097	0.060
25	0.128	0.132	0.114	0.121*	0.118*	0.436*	1.070*	0.612	0.136*	0.098*	0.077	0.079
26	0.130	0.130	0.115	0.121*	0.118*	0.456*	1.157*	0.551*	0.128*	0.098*	0.074	0.104
27	0.130	0.130	0.115	0.121*	0.118*	0.508*	1.474*	0.507*	0.122*	0.083	0.089	0.081
28	0.130	0.132	0.115	0.121*	0.117*	0.560*	1.695*	0.479*	0.116*	0.074	0.085	0.076
29	0.129	0.134	0.115	0.121*		0.650*	1.820*	0.455*	0.109*	0.074	0.077	0.074
30	0.130	0.133*	0.116	0.121*		0.615*	1.781*	0.433*	0.105*	0.072	0.089	0.071
31	0.130		0.118	0.121*		0.500*		0.411*		0.069	0.103	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	3.956	3.977	4.198	3.815	3.325	9.025	29.411	27.781	6.802	3.011	2.404	2.005
TOTAL FLOW (cms days)	0.112	0.113	0.119	0.108	0.094	0.256	0.833	0.787	0.193	0.085	0.068	0.057
TOTAL DEPTH (in)	0.324	0.325	0.343	0.312	0.272	0.738	2.406	2.272	0.556	0.246	0.197	0.164
TOTAL DEPTH (cm)	0.822	0.826	0.872	0.793	0.691	1.875	6.110	5.772	1.413	0.626	0.499	0.416

ANNUAL SUMMARY:
Sum of Mean Daily Flow 99.709 cfs = 2.824 cms
Total Depth 8.155 in = 20.715 cm
Maximum Instantaneous Flow 2.089 cfs = 0.059 cms on April 30 at 05.79 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 2
WATERSHED AREA: 291 ACRES (117 HECTARES)

WATER YEAR 1980
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.066	0.138	0.121	0.147	0.228*	0.668*	0.470	4.490	1.167	0.331	0.146	0.106
2	0.063	0.132	0.126	0.144	0.226*	0.662*	0.455	4.469	1.238	0.355*	0.140	0.147
3	0.060	0.131	0.185	0.143	0.227	0.631*	0.443	4.615	1.077	0.345	0.139	0.133
4	0.059	0.140	0.190	0.143*	0.206	0.622*	0.445	4.745	0.958	0.310	0.136	0.104
5	0.064	0.152	0.185	0.143*	0.201	0.595*	0.504	4.807	1.205	0.279	0.131	0.096
6	0.064	0.145	0.177	0.145	0.203	0.562*	0.549	4.637	1.165	0.265	0.129	0.093
7	0.061	0.138	0.175	0.150	0.202	0.535*	0.516	3.168	1.010	0.250	0.126	0.091
8	0.059	0.134	0.180	0.153	0.201	0.517*	0.501	2.704	0.911	0.242	0.121	0.095
9	0.065	0.131	0.201	0.151	0.201	0.504*	0.526	2.606	0.853	0.234	0.118	0.097
10	0.068	0.130	0.215*	0.148	0.206	0.512*	0.569	2.373	0.810*	0.224	0.112	0.172
11	0.069	0.125	0.205	0.146	0.216	0.502*	0.585	2.092	0.761*	0.217	0.107	0.228
12	0.069	0.123	0.193	0.218	0.223	0.483*	0.846	1.773	0.800	0.210	0.106	0.175
13	0.069	0.116	0.180	0.490	0.227	0.479*	1.622	1.530	0.710	0.210	0.102	0.245
14	0.070	0.101	0.168	1.017	0.224	0.492*	2.251	1.396	0.714	0.230	0.106	0.211
15	0.154	0.099	0.165	0.913	0.223	0.466*	2.738	1.383	0.711	0.245	0.240	0.177
16	0.103	0.102	0.162	0.599	0.221	0.451*	2.871	1.384	0.642*	0.229	0.160	0.147
17	0.108	0.114	0.160	0.463	0.229	0.449*	3.602*	1.273	0.595*	0.211	0.137	0.126
18	0.152	0.117	0.158	0.387	0.377	0.458*	4.820*	1.184	0.573*	0.204	0.154	0.172
19	0.305	0.111*	0.156	0.344	0.712	0.451*	5.301*	1.064	0.533*	0.197	0.137	0.166
20	0.186	0.113*	0.156	0.631	0.655	0.455*	6.319*	0.959	0.504*	0.189	0.127	0.180
21	0.173	0.115	0.157	0.292	0.559	0.454*	6.246*	0.931	0.474*	0.191	0.120	0.188
22	0.172	0.116	0.157	0.285	0.493	0.467*	6.103*	0.847	0.459*	0.182	0.120	0.170
23	0.237	0.118	0.153	0.275	0.439	0.480*	6.214*	0.923	0.467*	0.170	0.115	0.158
24	0.216	0.122	0.153	0.262	0.396	0.479*	5.753*	0.881	0.449	0.163	0.107	0.147
25	0.216	0.125	0.155	0.262	0.374	0.488*	4.525*	1.080	0.423	0.157	0.105	0.139
26	0.266	0.124	0.152	0.259	0.397	0.503*	4.305*	1.338	0.411	0.152	0.103	0.132
27	0.196	0.120	0.150	0.252	0.514*	0.509*	4.444*	1.419	0.403	0.146	0.108	0.128
28	0.177	0.119*	0.149	0.242*	0.633*	0.495	4.298*	1.370	0.381	0.140*	0.109	0.123
29	0.160	0.118*	0.154	0.239*	0.644*	0.510	3.816*	1.338	0.360	0.152*	0.107	0.121
30	0.151	0.119*	0.155	0.234*		0.506	4.268*	1.247	0.350	0.147	0.107	0.122
31	0.145		0.152	0.232*		0.489		1.134		0.153	0.107	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	4.022	3.689	5.145	9.510	9.856	15.876	85.905	65.158	21.113	6.728	3.882	4.389
TOTAL FLOW (cms days)	0.114	0.104	0.146	0.269	0.279	0.450	2.433	1.845	0.598	0.191	0.110	0.124
TOTAL DEPTH (in)	0.329	0.302	0.421	0.778	0.806	1.299	7.026	5.329	1.727	0.550	0.318	0.359
TOTAL DEPTH (cm)	0.836	0.766	1.069	1.976	2.048	3.298	17.847	13.537	4.386	1.398	0.806	0.912

ANNUAL SUMMARY:

Sum of Mean Daily Flow 235.275 cfs = 6.663 cms
Total Depth 19.244 in = 48.879 cm
Maximum Instantaneous Flow 8.353 cfs = 0.237 cms on April 20 at 17.51 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 2
WATERSHED AREA: 291 ACRES (117 HECTARES)

WATER YEAR 1981
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.120	0.155	0.190	0.652	0.249	0.738	0.774	1.736	0.531	0.248	0.159	0.083
2	0.120	0.150	0.242*	0.612	0.251	0.747	0.763	1.594	0.517	0.242	0.150	0.084
3	0.122	0.147	0.449	0.586	0.261	0.754	0.763	1.414	0.514	0.232	0.145	0.081
4	0.124	0.148	0.638	0.522	0.264	0.741	0.727	1.262	0.469	0.223	0.142	0.079
5	0.124	0.149	0.438	0.476	0.266	0.703	0.734	1.117	0.442	0.219	0.136	0.080
6	0.128	0.190	0.342	0.452	0.268	0.663	0.736	1.014	0.419	0.259	0.132	0.078
7	0.128	0.369	0.298	0.417	0.263	0.647	0.703	0.938	0.436	0.268	0.130	0.075
8	0.127	0.313	0.281	0.394	0.251	0.644	0.671	0.871	0.618	0.253	0.127	0.074
9	0.124	0.245	0.271	0.376	0.252	0.642	0.676	0.797	0.587	0.240	0.127	0.071
10	0.123	0.226	0.255	0.354	0.235	0.646	0.651	0.818	0.532	0.455	0.126	0.069
11	0.121	0.219	0.235	0.347	0.237	0.658	0.638	0.776	0.490	0.220	0.123	0.071
12	0.194	0.215	0.226	0.341	0.242	0.672	0.607	0.714	0.452	0.211	0.118	0.070
13	0.168	0.198*	0.223	0.327	0.269	0.692	0.594	0.674	0.449	0.203	0.095	0.068
14	0.160	0.189	0.225	0.318	0.345	0.703	0.621	0.663	0.444	0.200	0.089	0.067
15	0.157	0.186	0.231	0.305	0.337	0.722	0.743	0.773	0.431	0.194	0.087	0.066
16	0.150	0.181	0.262	0.298	0.618	0.753	0.953	0.714	0.409	0.190	0.083	0.066
17	0.148	0.184	0.299	0.294	1.015	0.693	1.082	0.651	0.406	0.186	0.081	0.066
18	0.148	0.183	0.302	0.284	0.781	0.642	1.354	0.608	0.398	0.181	0.089	0.065
19	0.147	0.182	0.293	0.279	1.539	0.604	2.169	0.620	0.374	0.175	0.092	0.073
20	0.291	0.183	0.282	0.277	1.424	0.599	3.194	0.652	0.361	0.170	0.101	0.081
21	0.144	0.185	0.301	0.274	0.958	0.613	2.781	0.686	0.345	0.165	0.086	0.085
22	0.141	0.195	0.645	0.270	0.831	0.623	2.208	0.676	0.332	0.166	0.086	0.087
23	0.141	0.188*	0.543	0.281	0.809	0.636	2.071	0.648	0.327	0.165	0.083	0.090
24	0.142	0.187*	0.443	0.291	0.826	0.623	2.287	0.615	0.321	0.166	0.079	0.091
25	0.159	0.185*	0.839	0.280	0.867	0.651	2.236	0.815	0.311	0.168	0.077	0.119
26	0.184	0.185	3.777	0.274	0.815	0.712	2.257	0.825	0.297	0.169	0.077	0.120
27	0.167	0.184	2.479	0.272	0.777	0.748	2.216	0.708	0.277	0.170	0.077	0.119
28	0.157	0.189	1.779	0.270	0.743	0.782	1.964	0.643	0.267	0.171	0.078	0.140
29	0.156	0.191	1.105	0.265		0.813	1.853	0.606	0.262	0.172	0.076	0.111
30	0.155	0.192	0.830	0.266		0.782	1.790	0.612	0.256	0.173	0.082	0.104
31	0.156		0.728	0.262		0.754		0.571		0.172	0.086	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	4.625	5.893	19.448	10.915	15.994	21.402	40.818	25.810	12.275	6.427	3.220	2.532
TOTAL FLOW (cms days)	0.131	0.167	0.551	0.309	0.453	0.606	1.156	0.731	0.348	0.182	0.091	0.072
TOTAL DEPTH (in)	0.378	0.482	1.591	0.893	1.308	1.750	3.339	2.111	1.004	0.526	0.263	0.207
TOTAL DEPTH (cm)	0.961	1.224	4.040	2.268	3.323	4.446	8.480	5.362	2.550	1.335	0.669	0.526

ANNUAL SUMMARY:
Sum of Mean Daily Flow 169.358 cfs = 4.796 cms
Total Depth 13.852 in = 35.185 cm
Maximum Instantaneous Flow 5.342 cfs = 0.151 cms on December 26 at 07.67 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 2
WATERSHED AREA: 291 ACRES (117 HECTARES)

WATER YEAR 1982
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.108	0.161	0.219	0.253	0.230	0.653	0.727	5.947	1.920	0.486	0.167	0.087
2	0.108	0.151	0.228	0.239	0.233	0.793	0.688	7.541	1.863	0.497	0.164	0.084
3	0.114	0.131	0.212	0.239	0.234	0.740	0.646	7.152	1.783	0.488	0.160	0.083
4	0.113	0.127	0.205	0.241	0.231	0.690	0.606	5.570	1.712	0.443	0.153	0.082
5	0.113	0.126	0.204	0.223	0.234	0.629	0.573	4.446	1.599	0.439	0.147	0.081
6	0.109	0.122	0.229	0.221	0.239	0.596	0.548	4.486*	1.467	0.408	0.137	0.079
7	0.152	0.121	0.234	0.221	0.241	0.585	0.525	4.746*	1.401	0.439	0.127	0.077
8	0.132	0.120	0.246	0.222	0.242	0.611	0.505	4.303	1.315	0.455	0.132	0.076
9	0.131	0.119	0.281	0.222	0.244	0.599	0.496	3.822	1.239	0.431	0.145	0.075
10	0.178	0.117	0.370	0.222	0.246	0.601	0.519	3.697	1.214	0.377	0.144	0.075
11	0.184	0.117	0.343	0.222	0.246	0.709	1.571	3.561	1.179	0.367	0.146	0.076
12	0.151	0.209	0.308	0.223	0.246	0.741	2.225	3.624	1.190	0.363	0.148	0.106
13	0.141	0.298	0.284	0.223	0.247	0.705	1.841	4.089	1.134	0.348	0.150	0.119
14	0.135	0.344	0.267	0.222	0.381*	0.676	1.960	4.826	1.049	0.329	0.148	0.115
15	0.132	0.274	0.274	0.222	0.487*	0.660	1.658	5.212	0.990	0.308	0.143	0.117
16	0.127	0.776	0.254	0.225	0.838*	0.626	1.422	5.596	0.908	0.286	0.136	0.117
17	0.126	0.638	0.238	0.230	0.727*	0.603	1.357	5.196	0.849	0.276	0.130	0.117
18	0.123	0.444	0.235	0.230	0.603*	0.589	1.295	5.170	0.793	0.266	0.119*	0.113
19	0.123	0.318	0.679	0.230	0.568	0.561	1.175	4.367	0.752	0.256	0.097*	0.157
20	0.123	0.265	1.445	0.232	0.666	0.535	1.114	4.080	0.707	0.241	0.097	0.314
21	0.123	0.346	0.695	0.233	1.699	0.516	1.389	4.307	0.655	0.228	0.093	0.192
22	0.123	0.552	0.500	0.230	2.032	0.500	2.228	4.386	0.602	0.218	0.086	0.164
23	0.122	0.390	0.414	0.230	1.276	0.488	3.613	4.147	0.563	0.214	0.085	0.143
24	0.122	0.325	0.376	0.232	0.963	0.507	4.529	3.897	0.531	0.211	0.085	0.135
25	0.124	0.283	0.345	0.232	0.826	0.699	4.749	4.044	0.583	0.206	0.084	0.158
26	0.143	0.262	0.326	0.232	0.735	1.013	4.571	3.948	0.523	0.193	0.079	0.298
27	0.136	0.251	0.311	0.231	0.674	1.143	5.223	3.137	0.501	0.189	0.076	0.183
28	0.169	0.229	0.300	0.230	0.613	0.997	5.246	2.683	0.522	0.191	0.076	0.163
29	0.164	0.229	0.289	0.231		0.902	4.779	2.346	0.484	0.194	0.075	0.208
30	0.150	0.223	0.270	0.231		0.833	4.909	2.143	0.448	0.187	0.083	0.228
31	0.155		0.263	0.230		0.775		2.001		0.177	0.087	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	4.151	8.065	10.845	7.103	16.201	21.272	62.686	134.469	30.477	9.712	3.702	4.020
TOTAL FLOW (cms days)	0.118	0.228	0.307	0.201	0.459	0.602	1.775	3.808	0.863	0.275	0.105	0.114
TOTAL DEPTH (in)	0.340	0.660	0.887	0.581	1.325	1.740	5.127	10.999	2.493	0.794	0.303	0.329
TOTAL DEPTH (cm)	0.862	1.676	2.253	1.476	3.366	4.419	13.023	27.936	6.332	2.018	0.769	0.835

ANNUAL SUMMARY:
Sum of Mean Daily Flow 312.703 cfs = 8.856 cms
Total Depth 25.577 in = 64.965 cm
Maximum Instantaneous Flow 9.349 cfs = 0.265 cms on May 2 at 19.56 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 3
WATERSHED AREA: 318 ACRES (128 HECTARES)

WATER YEAR 1965
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.267	0.361	0.397	0.623	0.774	0.614	1.037	4.767	1.240	0.699	0.453	0.414
2	0.272	0.417	0.391	0.606	0.767	0.611	1.260	4.203	1.164	0.679	0.469	0.411
3	0.278	0.344	0.369	0.588	0.706	0.614	1.185	3.748	1.117	0.658	0.473	0.408
4	0.283	0.332	0.357	0.566	0.562	0.621	1.192	3.381	1.090	0.650	0.458	0.408
5	0.292	0.325	0.350	0.568	0.558	0.649	1.267	3.023	1.066	0.637	0.447	0.409
6	0.292	0.320	0.346	0.566	0.549	0.710	1.333	2.730	1.029	0.630	0.438	0.410
7	0.291	0.318	0.342	0.543	0.538	0.782	1.339	2.490	1.019	0.621	0.431	0.423
8	0.323	0.317	0.342	0.522	0.532	0.850	1.419	2.406	0.980	0.627	0.425	0.428
9	0.304	0.320	0.346	0.518	0.525	0.921	1.540	2.392	0.931	0.628	0.429	0.421
10	0.301	0.337	0.359	0.518	0.516	0.963	1.492	2.448	0.914	0.602	0.420	0.413
11	0.296	0.336	0.347	0.518	0.509	1.035	1.455	2.594	0.885	0.593	0.429	0.407
12	0.300	0.341	0.338	0.516	0.503	1.009	1.602	2.785	0.866	0.585	0.525	0.410
13	0.297	0.326	0.322	0.513	0.502	0.997	1.999	2.969	0.918	0.570	0.480	0.403
14	0.299	0.321	0.340	0.513	0.498	1.000	2.494	3.068	0.877	0.555	0.453	0.406
15	0.384	0.315	0.341	0.518	0.491	0.999	3.074	2.903	0.860	0.548	0.444	0.441
16	0.329	0.312	0.330	0.523	0.490	0.991	3.543	2.808	0.892	0.540	0.443	0.425
17	0.310	0.315	0.332	0.528	0.494	0.983	3.225	2.587	0.848	0.544	0.428	0.414
18	0.306	0.316	0.341	0.534	0.499	0.949	2.841	2.328	0.810	0.537	0.422	0.410
19	0.309	0.313	0.347	0.538	0.504	0.905	5.392	2.201	0.779	0.537	0.527	0.410
20	0.312	0.312	0.348	0.541	0.517	0.861	8.403	2.130	0.748	0.550	0.502	0.411
21	0.312	0.311	0.597	0.543	0.535	0.828	6.275	2.084	0.730	0.535	0.522	0.410
22	0.312	0.312	2.733	0.541	0.538	0.799	5.650	2.103	0.710	0.522	0.495	0.413
23	0.312	0.320	2.920	0.549	0.534	0.771	5.161	2.094	0.728	0.514	0.475	0.411
24	0.312	0.415	2.126	0.551	0.532	0.747	4.850	1.962	0.745	0.506	0.450	0.409
25	0.312	0.553	1.614	0.545	0.541	0.734	4.810	1.847	0.726	0.502	0.446	0.404
26	0.319	0.390	1.215	0.545	0.562	0.730	4.710	1.739	0.727	0.500	0.450	0.400
27	0.318	0.364	1.013	0.563	0.679	0.714	4.726	1.644	0.708	0.491	0.448	0.399
28	0.315	0.365	0.868	0.570	0.624	0.698	4.720	1.512	0.688	0.481	0.447	0.401
29	0.313	0.354	0.778	0.677		0.708	4.884	1.408	0.679	0.469	0.445	0.394
30	0.313	0.389	0.713	0.768		0.712	4.954	1.347	0.678	0.462	0.443	0.392
31	0.313		0.663	0.794		0.802		1.294		0.454	0.430	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	9.499	10.373	22.222	17.506	15.576	25.305	97.834	76.994	26.153	17.426	14.148	12.316
TOTAL FLOW (cms days)	0.269	0.294	0.629	0.496	0.441	0.717	2.771	2.180	0.741	0.494	0.401	0.349
TOTAL DEPTH (in)	0.711	0.776	1.663	1.310	1.166	1.894	7.323	5.763	1.957	1.304	1.059	0.922
TOTAL DEPTH (cm)	1.806	1.972	4.225	3.328	2.961	4.811	18.600	14.638	4.972	3.313	2.690	2.341

ANNUAL SUMMARY:
Sum of Mean Daily Flow 345.352 cfs = 9.780 cms
Total Depth 25.849 in = 65.656 cm
Maximum Instantaneous Flow 8.760 cfs = 0.248 cms on April 20 at 03.25 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 3
WATERSHED AREA: 318 ACRES (128 HECTARES)

WATER YEAR 1966
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.383	0.358	0.408	0.308	0.390	0.344	1.780	0.733	0.386	0.269	0.241	0.239
2	0.366	0.358	0.419	0.308	0.390	0.341	1.704	0.775	0.366	0.284	0.239	0.237
3	0.365	0.355	0.418	0.306	0.390	0.341	1.418	0.824	0.359	0.279	0.239	0.236
4	0.366	0.363	0.425	0.303	0.390	0.343	1.242	0.874	0.352	0.276	0.243	0.233
5	0.372	0.360	0.437	0.305	0.389	0.347	1.192	0.896	0.348	0.272	0.242	0.238
6	0.371	0.357	0.437	0.541	0.386	0.348	1.261	0.871	0.340	0.262	0.239	0.236
7	0.370	0.352	0.430	0.440	0.382	0.346	1.356	0.804	0.344	0.261	0.238	0.235
8	0.372	0.350	0.425	0.388	0.380	0.329	1.459	0.742	0.338	0.257	0.241	0.227
9	0.368	0.350	0.418	0.360	0.380	0.340	1.474	0.715	0.361	0.257	0.244	0.227
10	0.361	0.358	0.430	0.357	0.380	0.390	1.513	0.653	0.350	0.258	0.242	0.227
11	0.363	0.380	0.427	0.357	0.379	0.381	1.450	0.596	0.335	0.252	0.243	0.228
12	0.364	0.381	0.425	0.358	0.377	0.396	1.322	0.564	0.326	0.253	0.241	0.228
13	0.362	0.385	0.419	0.360	0.377	0.536	1.203	0.537	0.326	0.252	0.241	0.261
14	0.374	0.528	0.411	0.360	0.377	0.509	1.160	0.534	0.326	0.248	0.246	0.311
15	0.464	0.492	0.400	0.359	0.379	0.469	1.208	0.516	0.325	0.247	0.240	0.331
16	0.393	0.443	0.400	0.358	0.382	0.432	1.294	0.502	0.322	0.241	0.236	0.295
17	0.376	0.446	0.401	0.359	0.385	0.403	1.238	0.476	0.320	0.240	0.235	0.284
18	0.375	0.463	0.404	0.360	0.385	0.396	1.107	0.457	0.313	0.238	0.233	0.283
19	0.433	0.447	0.407	0.361	0.385	0.397	1.004	0.443	0.309	0.238	0.237	0.288
20	0.379	0.438	0.409	0.365	0.384	0.386	0.915	0.431	0.308	0.258	0.240	0.283
21	0.369	0.438	0.413	0.370	0.381	0.381	0.852	0.429	0.311	0.257	0.239	0.274
22	0.370	0.434	0.417	0.375	0.375	0.373	0.811	0.434	0.311	0.255	0.239	0.273
23	0.363	0.439	0.421	0.377	0.375	0.375	0.794	0.413	0.321	0.255	0.237	0.269
24	0.360	0.432	0.425	0.379	0.371	0.392	0.808	0.404	0.317	0.255	0.233	0.269
25	0.360	0.423	0.425	0.382	0.370	0.480	0.852	0.393	0.302	0.252	0.233	0.273
26	0.359	0.427	0.423	0.385	0.369	0.652	0.845	0.381	0.292	0.252	0.248	0.282
27	0.359	0.432	0.426	0.388	0.359	0.830	0.801	0.377	0.284	0.251	0.248	0.281
28	0.361	0.421	0.404	0.390	0.339	0.989	0.778	0.381	0.279	0.249	0.243	0.278
29	0.363	0.416	0.344	0.390		1.232	0.750	0.374	0.278	0.248	0.248	0.276
30	0.362	0.411	0.324	0.390		1.443	0.731	0.364	0.272	0.247	0.248	0.275
31	0.359		0.312	0.390		1.683		0.376		0.245	0.242	

MONTHLY SUMMARY:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	11.561	12.235	12.682	11.428	10.608	16.604	34.321	17.270	9.721	7.910	7.460	7.873
TOTAL FLOW (cms days)	0.327	0.346	0.359	0.324	0.300	0.470	0.972	0.489	0.275	0.224	0.211	0.223
TOTAL DEPTH (in)	0.865	0.916	0.949	0.855	0.794	1.243	2.569	1.293	0.728	0.592	0.558	0.589
TOTAL DEPTH (cm)	2.198	2.326	2.411	2.173	2.017	3.157	6.525	3.283	1.848	1.504	1.418	1.497

ANNUAL SUMMARY:
Sum of Mean Daily Flow 159.672 cfs = 4.522 cms
Total Depth 11.951 in = 30.356 cm
Maximum Instantaneous Flow 1.974 cfs = 0.056 cms on March 31 at 21.50 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 3
WATERSHED AREA: 318 ACRES (128 HECTARES)

WATER YEAR 1967
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.275	0.303	0.384	0.289	0.399	0.367	0.497	0.734	0.890	0.362	0.272	0.277
2	0.311	0.301	0.372	0.289	0.386	0.382	0.501	0.759	0.812	0.354	0.276	0.278
3	0.286	0.299	0.365	0.289	0.380	0.367	0.551	0.837	0.769	0.357	0.285	0.278
4	0.282	0.299	0.351	0.303	0.373	0.362	0.605	1.008	0.735	0.349	0.286	0.285
5	0.281	0.307	0.353	0.310	0.364	0.359	0.602	1.252	0.721	0.336	0.283	0.284
6	0.280	0.342	0.337	0.310	0.359	0.368	0.602	1.601	0.720	0.331	0.252	0.291
7	0.278	0.331	0.335	0.310	0.357	0.383	0.671	2.210	0.706	0.333	0.277	0.298
8	0.284	0.315	0.329	0.309	0.355	0.379	0.740	2.763	0.671	0.331	0.276	0.301
9	0.281	0.311	0.319	0.308	0.356	0.378	0.814	3.064	0.652	0.329	0.281	0.298
10	0.278	0.313	0.328	0.308	0.356	0.378	0.924	2.904	0.630	0.328	0.282	0.286
11	0.278	0.313	0.330	0.309	0.347	0.374	0.980	2.397	0.615	0.326	0.278	0.370
12	0.317	0.364	0.334	0.310	0.346	0.360	1.022	2.014	0.607	0.319	0.275	0.317
13	0.297	0.378	0.342	0.326	0.347	0.356	1.045	1.733	0.565	0.317	0.263	0.302
14	0.290	0.373	0.332	0.349	0.342	0.343	1.049	1.654	0.542	0.314	0.263	0.300
15	0.290	0.376	0.323	0.341	0.336	0.342	0.943	1.826	0.521	0.309	0.263	0.297
16	0.290	0.486	0.322	0.331	0.336	0.404	0.867	2.129	0.511	0.316	0.299	0.295
17	0.289	0.350	0.323	0.318	0.339	0.555	0.819	2.470	0.506	0.352	0.284	0.294
18	0.289	0.328	0.327	0.314	0.337	0.539	0.808	2.547	0.486	0.309	0.281	0.292
19	0.289	0.325	0.331	0.316	0.330	0.497	0.794	2.387	0.465	0.303	0.282	0.295
20	0.288	0.387	0.331	0.332	0.329	0.478	0.761	2.162	0.482	0.300	0.280	0.293
21	0.288	0.382	0.322	0.337	0.329	0.474	0.720	1.979	0.523	0.302	0.281	0.291
22	0.297	0.345	0.315	0.323	0.329	0.483	0.700	1.794	0.480	0.294	0.281	0.287
23	0.315	0.326	0.313	0.312	0.331	0.530	0.701	1.592	0.454	0.286	0.281	0.287
24	0.309	0.319	0.313	0.312	0.338	0.555	0.714	1.414	0.432	0.268	0.277	0.287
25	0.304	0.316	0.312	0.312	0.340	0.546	0.738	1.217*	0.424	0.260	0.276	0.285
26	0.297	0.314	0.311	0.317	0.343	0.541	0.762	1.102*	0.409	0.254	0.279	0.283
27	0.289	0.311	0.308	0.338	0.360	0.538	0.794	1.062*	0.411	0.258	0.281	0.284
28	0.295	0.312	0.307	0.419	0.381	0.548	0.790	1.004*	0.398	0.255	0.282	0.285
29	0.301	0.369	0.310	0.590		0.550	0.760	0.992*	0.380	0.249	0.278	0.284
30	0.302	0.343	0.302	0.518		0.519	0.737	0.948	0.373	0.245	0.280	0.429
31	0.303		0.291	0.441		0.509		0.869		0.280	0.279	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	9.054	10.136	10.175	10.490	9.826	13.763	23.013	52.422	16.890	9.526	8.611	8.929
TOTAL FLOW (cms days)	0.256	0.287	0.288	0.297	0.278	0.390	0.652	1.485	0.478	0.270	0.244	0.253
TOTAL DEPTH (in)	0.678	0.759	0.762	0.785	0.735	1.030	1.722	3.924	1.264	0.713	0.645	0.668
TOTAL DEPTH (cm)	1.721	1.927	1.934	1.994	1.868	2.617	4.375	9.966	3.211	1.811	1.637	1.698

ANNUAL SUMMARY:
Sum of Mean Daily Flow 182.837 cfs = 5.178 cms
Total Depth 13.685 in = 34.760 cm
Maximum Instantaneous Flow 3.240 cfs = 0.092 cms on May 9 at 19.50 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 3
WATERSHED AREA: 318 ACRES (128 HECTARES)

WATER YEAR 1968
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.352	0.306	0.295	0.281	0.271	0.755	0.840	0.692	0.393	0.279	0.234	0.222
2	0.343	0.300	0.294	0.276	0.274	0.776	0.950	0.672	0.384	0.274	0.237	0.229
3	0.476	0.299	0.298	0.274	0.280	0.822	0.942	0.654	0.386	0.270	0.239	0.224
4	0.322	0.300	0.306	0.276	0.284	0.894	0.923	0.648	0.378	0.266	0.237	0.234
5	0.328	0.298	0.308	0.275	0.291	0.972	1.017	0.638	0.375	0.261	0.237	0.252
6	0.320	0.297	0.297	0.271	0.295	0.925	0.948	0.604	0.404	0.256	0.237	0.240
7	0.312	0.296	0.298	0.271	0.300	0.891*	0.888	0.592	0.389	0.255	0.235	0.233
8	0.310	0.297	0.296	0.279	0.301	0.896*	0.842	0.581*	0.380*	0.255	0.235	0.220
9	0.308	0.318	0.295	0.276	0.306	0.876*	0.829	0.578*	0.376*	0.258	0.236	0.206
10	0.310	0.343	0.294	0.277	0.312	0.856*	0.894	0.569*	0.369*	0.256	0.246*	0.212
11	0.309	0.358	0.294	0.264	0.319	0.837*	1.021	0.561*	0.362*	0.256	0.253*	0.238
12	0.312	0.349	0.287	0.262	0.322	0.817*	1.011	0.552*	0.352	0.270	0.264*	0.241
13	0.312	0.336	0.277	0.266	0.318	0.798*	0.936	0.544*	0.359	0.268	0.284	0.242
14	0.312	0.327	0.274	0.269	0.312	0.779*	0.880	0.535*	0.355	0.262	0.371	0.257
15	0.312	0.319	0.272	0.275	0.308	0.758*	0.835	0.527*	0.353	0.258	0.332	0.274
16	0.310	0.310	0.270	0.280	0.302	0.738*	0.779	0.519*	0.354	0.255	0.259	0.264
17	0.305	0.305	0.266	0.270	0.297	0.719*	0.726	0.510*	0.347	0.253	0.263	0.256
18	0.305	0.317	0.262	0.269	0.338	0.699*	0.700	0.502*	0.326	0.247	0.303	0.267
19	0.305	0.312	0.259	0.269	0.711	0.680*	0.666	0.494*	0.307	0.244	0.288	0.268
20	0.306	0.308	0.252	0.269	1.287	0.660*	0.633	0.486*	0.317	0.244	0.328	0.286
21	0.323	0.304	0.246	0.269	0.981	0.641*	0.610	0.478*	0.301	0.240	0.357	0.308
22	0.325*	0.301	0.247	0.271	0.757	0.621*	0.592	0.466	0.320	0.237	0.347	0.293
23	0.332*	0.300	0.250	0.276	0.837	0.595	0.585	0.453	0.318	0.236	0.296	0.282
24	0.317	0.309	0.250	0.279	0.817	0.631	0.593	0.439	0.297	0.236	0.270	0.274
25	0.310	0.302	0.308	0.282	0.720	0.644	0.584	0.516	0.291	0.235	0.248	0.263
26	0.301	0.295	0.338	0.278	0.656	0.638	0.568	0.497	0.287	0.231	0.244	0.257
27	0.346	0.294	0.295	0.278	0.620	0.617	0.556	0.471	0.281	0.230	0.241	0.255
28	0.489	0.297	0.287	0.274	0.634	0.638	0.573	0.446	0.287	0.233	0.240	0.252
29	0.340	0.304	0.284	0.274	0.691	0.708	0.619	0.426	0.289	0.234	0.232	0.250
30	0.320	0.304	0.280	0.274		0.787	0.680	0.415	0.289	0.230	0.230	0.243
31	0.311		0.278	0.272		0.801		0.405		0.232	0.223	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	10.183	9.306	8.757	8.475	14.143	23.468	23.221	16.467	10.224	7.764	8.245	7.540
TOTAL FLOW (cms days)	0.288	0.264	0.248	0.240	0.401	0.665	0.658	0.466	0.290	0.220	0.234	0.214
TOTAL DEPTH (in)	0.762	0.696	0.655	0.634	1.059	1.757	1.738	1.233	0.765	0.581	0.617	0.564
TOTAL DEPTH (cm)	1.936	1.769	1.665	1.611	2.689	4.462	4.415	3.131	1.944	1.476	1.568	1.433

ANNUAL SUMMARY:
Sum of Mean Daily Flow 147.794 cfs = 4.186 cms
Total Depth 11.062 in = 28.098 cm
Maximum Instantaneous Flow 1.628 cfs = 0.046 cms on February 20 at 01.20 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 3
WATERSHED AREA: 318 ACRES (128 HECTARES)

WATER YEAR 1969
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.238	0.239	0.269	0.232	0.277	0.245	1.861	1.758	0.625	0.467	0.322	0.259
2	0.237	0.238	0.268	0.233	0.268	0.247	2.032	1.667	0.610	0.461	0.319	0.244
3	0.238	0.258	0.267	0.229	0.265	0.249	2.128	1.603	0.606	0.455	0.320	0.245
4	0.238	0.256	0.269	0.233	0.260	0.252	2.186	1.649	0.591	0.451	0.319	0.245
5	0.238	0.249	0.272	0.272	0.257	0.261	2.479	1.752	0.568	0.448	0.317	0.250
6	0.236	0.247	0.265	0.297	0.253	0.261	2.993	1.886	0.550	0.439*	0.314	0.250
7	0.234	0.248	0.262	0.286	0.248	0.258	2.487	2.025	0.530	0.420	0.318	0.244
8	0.235	0.255	0.262	0.275	0.246	0.256	2.147	2.073	0.531	0.413	0.305	0.239
9	0.236	0.332	0.262	0.270	0.245	0.251	2.259	2.020	0.531	0.400	0.300	0.244
10	0.236	0.282	0.276	0.266	0.246	0.247	2.491	1.905	0.526	0.396	0.303	0.250
11	0.262	0.316	0.296	0.266	0.248	0.246	2.503	1.763	0.507	0.393	0.321	0.255
12	0.305	0.419	0.273	0.263	0.253	0.245	2.656	1.622	0.491	0.396	0.314	0.254
13	0.311	0.320	0.267	0.301	0.250	0.246	2.847	1.492	0.471	0.391	0.306	0.253
14	0.290	0.289	0.266	0.298	0.247	0.252	2.718	1.572	0.477	0.382	0.307	0.249
15	0.278	0.284	0.268	0.289	0.245	0.265	2.550	1.390	0.478	0.370	0.300	0.248
16	0.268	0.273	0.274	0.282	0.247	0.282	2.540	1.218	0.467	0.357	0.300	0.246
17	0.260	0.269	0.266	0.279	0.249	0.295	2.628	1.101	0.457	0.356	0.299	0.242
18	0.255	0.296	0.262	0.276	0.249	0.312	3.051	1.052	0.449	0.356	0.303	0.247
19	0.247	0.291	0.262	0.281	0.247	0.301	2.725	1.015	0.469	0.357	0.292	0.281
20	0.260	0.286	0.255	0.292	0.244	0.297	2.514	1.000	0.503	0.351	0.292	0.309
21	0.253	0.284	0.247	0.554	0.243	0.313	2.700	0.895	0.485	0.346	0.289	0.263
22	0.252	0.356	0.245	0.449	0.243	0.344	3.437	0.834	0.479	0.345	0.284	0.253
23	0.247	0.327	0.245	0.385	0.244	0.364	4.153	0.792	0.518	0.344	0.279	0.264
24	0.246	0.309	0.249*	0.353	0.245	0.363	3.917	0.743	0.686	0.345	0.276	0.261
25	0.243	0.295	0.242	0.338	0.246	0.394	2.841	0.720	0.565	0.346	0.277	0.252
26	0.236	0.287	0.243	0.340	0.246	0.497	2.435	0.731	0.520	0.339	0.280	0.251
27	0.233	0.285	0.242	0.315	0.245	0.600	2.217	0.710	0.510	0.338	0.271	0.248
28	0.232	0.277	0.256	0.305	0.245	0.644	2.104	0.671	0.500	0.334	0.267	0.250
29	0.232	0.274	0.241	0.296		0.830	2.041	0.639	0.488	0.332	0.267	0.249
30	0.243	0.275	0.236	0.289		1.151	1.879	0.679	0.476	0.331	0.266	0.260
31	0.236		0.230	0.284		1.747		0.648		0.326	0.265	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	7.757	8.618	8.035	9.329	6.999	12.517	77.519	39.626	15.664	11.786	9.193	7.605
TOTAL FLOW (cms days)	0.220	0.244	0.228	0.264	0.198	0.354	2.195	1.122	0.444	0.334	0.260	0.215
TOTAL DEPTH (in)	0.581	0.645	0.601	0.698	0.524	0.937	5.802	2.966	1.172	0.882	0.688	0.569
TOTAL DEPTH (cm)	1.475	1.638	1.527	1.774	1.331	2.380	14.737	7.533	2.978	2.241	1.748	1.446

ANNUAL SUMMARY:
Sum of Mean Daily Flow 214.647 cfs = 6.079 cms
Total Depth 16.066 in = 40.807 cm
Maximum Instantaneous Flow 4.882 cfs = 0.138 cms on April 23 at 16.75 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 3
WATERSHED AREA: 318 ACRES (128 HECTARES)

WATER YEAR 1970
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.264	0.219	0.196	0.258	0.342	0.553	0.683	0.872	1.067	0.613	0.364	0.289*
2	0.296	0.217	0.191	0.258	0.340	0.535	0.667	1.143	0.998	0.572	0.359	0.284
3	0.250	0.215	0.191	0.258	0.338	0.511	0.658	1.664	0.946	0.545	0.356	0.285
4	0.246	0.213	0.195	0.258	0.328	0.492	0.678	2.365	0.901	0.536	0.356	0.335
5	0.244	0.233	0.194	0.258	0.324	0.472	0.837	3.201	0.855	0.518	0.371	0.333
6	0.242	0.264	0.191	0.259	0.331	0.459	1.212	3.621	0.831	0.510	0.354	0.316
7	0.243	0.242	0.191	0.264	0.341	0.470	1.441	3.508	0.812	0.503	0.348	0.315
8	0.288	0.227	0.191	0.267	0.349	0.512	1.285	3.065	0.785	0.492	0.345	0.401
9	0.280	0.224	0.191	0.268	0.367	0.499	1.280	3.186	0.828	0.485	0.341	0.294
10	0.267	0.222	0.191	0.269	0.384	0.506	1.684	2.937	0.777	0.507	0.338	0.288
11	0.263	0.221	0.193	0.269	0.406	0.517	1.627	2.546	0.730	0.477	0.342	0.286
12	0.260	0.219	0.204	0.269	0.467	0.517	1.373	2.241	0.716	0.463	0.348	0.292
13	0.260	0.217	0.221	0.283	0.483	0.508	1.245	1.975	0.725	0.456	0.349	0.294
14	0.260	0.213	0.224	0.299	0.447	0.553	1.137	1.839	0.844	0.447	0.345	0.299
15	0.260	0.218	0.224	0.308	0.418	0.616	1.034	1.874	0.807	0.446	0.341	0.303
16	0.262	0.224	0.220	0.304	0.412	0.628	0.980	2.236	0.755	0.435	0.336*	0.306*
17	0.262	0.221	0.223	0.307	0.462	0.611	1.006	2.833	0.706	0.436	0.330*	0.303
18	0.261	0.218	0.225	0.308	0.424	0.589	1.036	3.353	0.667	0.419	0.327	0.306
19	0.259	0.220	0.234	0.333	0.409	0.576	1.030	3.175	0.642	0.412	0.324	0.376
20	0.258	0.225	0.249	0.359	0.413	0.578	0.977	2.801	0.621	0.406	0.314	0.359
21	0.258	0.226	0.394	0.406	0.424	0.596	0.946	2.516	0.621*	0.403	0.307	0.345
22	0.258	0.223	0.290	0.453	0.440	0.621	0.910	2.322	0.627*	0.400	0.304	0.344
23	0.257	0.220	0.264	0.595	0.458	0.638	0.883	2.356	0.611*	0.392	0.301	0.345
24	0.256	0.219	0.259	0.875	0.477	0.658	0.863	2.104	0.574*	0.390	0.300	0.335
25	0.256	0.215	0.256	0.514	0.494	0.671	0.837	1.937	0.515*	0.384	0.297	0.329
26	0.261	0.215	0.259	0.417	0.512	0.690	0.813	1.770	0.474*	0.370	0.296	0.327
27	0.270	0.208	0.255*	0.401*	0.531	0.720	0.792	1.656	0.623	0.377	0.296	0.328
28	0.290	0.204	0.248	0.370	0.541	0.744	0.771	1.466	0.630	0.386	0.299	0.324
29	0.264	0.199	0.246	0.356		0.712	0.766	1.357	0.763	0.378	0.291	0.323
30	0.227	0.199	0.255*	0.346		0.686	0.774	1.243	0.667	0.372	0.288	0.325
31	0.223		0.261	0.341		0.684		1.141		0.367	0.291*	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	8.048	6.600	7.125	10.728	11.660	18.121	30.225	70.301	22.116	13.899	10.155	9.591
TOTAL FLOW (cms days)	0.228	0.187	0.202	0.304	0.330	0.513	0.856	1.991	0.626	0.394	0.288	0.272
TOTAL DEPTH (in)	0.602	0.494	0.533	0.803	0.873	1.356	2.262	5.262	1.655	1.040	0.760	0.718
TOTAL DEPTH (cm)	1.530	1.255	1.355	2.040	2.217	3.445	5.746	13.365	4.205	2.642	1.931	1.823

ANNUAL SUMMARY:
Sum of Mean Daily Flow 218.569 cfs = 6.190 cms
Total Depth 16.359 in = 41.553 cm
Maximum Instantaneous Flow 3.853 cfs = 0.109 cms on May 6 at 16.00 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 3
WATERSHED AREA: 318 ACRES (128 HECTARES)

WATER YEAR 1971
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.324	0.364	0.439	0.519	0.569	0.569	0.941	4.939	1.365	0.768	0.476	0.390
2	0.322	0.362	0.428	0.526	0.578	0.571	0.985	5.629*	1.311	0.754	0.484	0.393
3	0.319	0.355	0.416*	0.527	0.574	0.571	1.091	6.108*	1.248	0.725	0.472	0.392
4	0.318	0.353	0.417*	0.528	0.574	0.564	1.240	7.270	1.210	0.703	0.461	0.385
5	0.320	0.405	0.406	0.530	0.574	0.556	1.523	7.912	1.154	0.694	0.451	0.376
6	0.318	0.435	0.450	0.531	0.574	0.556	1.978	6.843	1.112	0.678	0.456	0.396
7	0.317	0.433	0.461	0.531	0.574	0.556	2.674	6.364	1.068	0.660	0.455	0.412
8	0.313	0.399	0.458	0.533	0.575	0.556	2.521	6.077	1.033	0.645	0.446	0.385
9	0.336	0.503	0.448	0.537	0.578	0.555	2.423	5.904	0.995	0.636	0.440	0.374
10	0.348	0.469	0.429	0.540	0.579	0.552	2.440	5.461	1.025	0.622	0.435	0.368
11	0.322	0.420	0.438	0.540	0.579	0.551	2.229	5.039	0.961	0.614	0.433	0.361
12	0.316	0.409	0.430	0.548	0.582	0.551	2.066	4.755	0.902	0.603	0.429	0.357
13	0.314	0.386	0.431	0.556	0.585	0.551	2.138	4.613	0.898	0.598	0.429	0.356
14	0.312	0.374	0.431	0.558	0.585	0.544	2.615	4.019	0.886*	0.594	0.431	0.363
15	0.311	0.369	0.431	0.561	0.585	0.537	3.159	3.561	0.874*	0.582	0.422	0.365
16	0.314	0.371	0.431	0.564	0.585	0.537	3.114	3.206	0.859*	0.583	0.420	0.360
17	0.314	0.368	0.431	0.565	0.584	0.537	3.141	2.828	0.845*	0.576	0.423	0.362
18	0.314	0.367	0.432	0.565	0.581	0.537	3.026	2.558	0.830*	0.559	0.418	0.368
19	0.326	0.365	0.436	0.565	0.578	0.537	3.398	2.319	0.800	0.564	0.414	0.360
20	0.338	0.370	0.442	0.565	0.575	0.537	3.994	2.095	0.769	0.559	0.404	0.348
21	0.332	0.359	0.466	0.565	0.574	0.537	4.470	1.960	0.751	0.541	0.406	0.352
22	0.348	0.356	0.476	0.571	0.574	0.537	4.432	1.848	0.734	0.534	0.404	0.354
23	0.355	0.448	0.470	0.576	0.574	0.530	3.955	1.771	0.722	0.531	0.403	0.349
24	0.361	1.247	0.479	0.578	0.574	0.570	3.607	1.743	0.699	0.511	0.391	0.348
25	0.352	0.942	0.486	0.579	0.572	0.643	3.520	1.706	0.784	0.507	0.394	0.355
26	0.341	0.645	0.491	0.579	0.571	0.733	3.582	1.637	1.049	0.500	0.391	0.370
27	0.335	0.547	0.501	0.578	0.569	0.746	3.626	1.577	0.975	0.496	0.389	0.374
28	0.346	0.506	0.508	0.575	0.568	0.722	3.898	1.529	0.954	0.490	0.387	0.377
29	0.350	0.468	0.509	0.574		0.754	4.188	1.476	0.858	0.488	0.396	0.401
30	0.359	0.465	0.510	0.574		0.921	4.354	1.457	0.803	0.480	0.401	0.396
31	0.362		0.512	0.572		0.951		1.387		0.480	0.395	

MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	10.258	13.863	14.093	17.206	16.140	18.667	86.329	115.591	28.474	18.275	13.157	11.147
TOTAL FLOW (cms days)	0.291	0.393	0.399	0.487	0.457	0.529	2.445	3.274	0.806	0.518	0.373	0.316
TOTAL DEPTH (in)	0.768	1.038	1.055	1.288	1.208	1.397	6.462	8.652	2.131	1.368	0.985	0.834
TOTAL DEPTH (cm)	1.950	2.636	2.679	3.271	3.068	3.549	16.412	21.975	5.413	3.474	2.501	2.119

ANNUAL SUMMARY:
Sum of Mean Daily Flow 363.200 cfs = 10.286 cms
Total Depth 27.185 in = 69.049 cm
Maximum Instantaneous Flow 9.079 cfs = 0.257 cms on May 4 at 21.75 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 3
WATERSHED AREA: 318 ACRES (128 HECTARES)

WATER YEAR 1972
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.399	0.386	0.370	0.312	0.360	0.542	1.054	2.509	1.006	0.548	0.410	0.347
2	0.387	0.377	0.368	0.317	0.359	0.495	1.287	2.579	0.964	0.544	0.404	0.343
3	0.382	0.378	0.370	0.310	0.356	0.562	1.494	2.896	0.939	0.531	0.403	0.341
4	0.376	0.378	0.370	0.304	0.352	0.505	1.576	3.415	0.904	0.513	0.423	0.342
5	0.371	0.373	0.374*	0.300	0.346	0.453	1.899	3.735	0.841	0.496	0.398	0.398
6	0.368	0.368	0.379	0.297	0.343	0.449	2.448	3.855	0.816*	0.487	0.411	0.383
7	0.361	0.368	0.366	0.296	0.345	0.443	2.375	3.809	0.840*	0.484	0.393	0.356
8	0.355	0.366	0.367	0.295	0.342	0.459	2.153	3.868	0.935	0.470	0.386	0.348
9	0.358	0.373	0.376	0.300	0.341	0.577	2.115	3.467	1.103	0.474	0.385	0.348
10	0.367	0.379	0.371	0.295	0.339	0.908	2.027	3.108	1.134	0.467	0.386	0.350
11	0.366	0.399	0.367	0.308*	0.337	1.284	1.912	2.957	1.019	0.459	0.389	0.362
12	0.366	0.419	0.357*	0.329	0.339	1.188	1.822	2.927	0.938	0.450	0.380	0.366
13	0.365	0.407	0.339	0.323	0.351	1.284	1.622	3.043	0.884	0.442	0.376	0.364*
14	0.366	0.394	0.328*	0.324	0.345	1.388	1.492	3.209	0.827	0.429	0.410	0.359*
15	0.370	0.380	0.311*	0.324	0.347	1.471	1.436	3.275	0.791	0.445	0.424	0.368
16	0.373	0.376	0.308	0.324	0.352	1.721	1.453	3.136	0.766	0.433	0.393	0.366
17	0.375	0.371	0.310	0.327	0.360	2.255	1.389	2.924	0.727	0.421	0.378	0.373
18	0.374	0.369	0.310	0.340	0.376	2.546	1.324	2.579	0.705	0.417	0.371	0.376
19	0.386	0.368	0.311	0.367	0.375	2.161	1.362	2.346	0.696	0.444	0.371	0.401
20	0.432	0.371	0.310	0.380	0.393	1.812	1.505	2.162	0.680	0.442	0.371	0.399
21	0.395	0.373	0.314	0.394	0.407	1.753	1.693	1.984	0.668	0.442	0.369	0.396
22	0.385	0.373	0.347	0.387	0.401	2.106	1.791	1.864	0.659	0.446	0.360	0.395
23	0.382	0.368	0.354	0.380	0.385	2.486	2.020	1.719	0.654	0.433	0.363	0.387
24	0.377	0.378	0.335	0.375	0.374	1.957	2.221	1.599	0.638	0.443	0.358	0.394
25	0.375	0.377	0.335	0.373	0.368	1.629	2.091	1.485	0.697	0.438	0.356	0.394
26	0.384	0.378*	0.331	0.369	0.365	1.374	2.057	1.393	0.634	0.449	0.351	0.390
27	0.383	0.381	0.325	0.367	0.535	1.206	2.399	1.303	0.607	0.434	0.347	0.403
28	0.376	0.378	0.321	0.365	0.900	1.087	3.061	1.236	0.591	0.418	0.388	0.378
29	0.371	0.385	0.319	0.366	0.806	0.991	3.081	1.181	0.579	0.411	0.375	0.377
30	0.374	0.404	0.317	0.367		0.936	2.601	1.123	0.565	0.410	0.366	0.371
31	0.375		0.313	0.360		0.982		1.070		0.413	0.352	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	11.675	11.393	10.571	10.477	11.601	39.009	56.759	77.753	23.805	14.129	11.847	11.177
TOTAL FLOW (cms days)	0.331	0.323	0.299	0.297	0.329	1.105	1.607	2.202	0.674	0.400	0.336	0.317
TOTAL DEPTH (in)	0.874	0.853	0.791	0.784	0.868	2.920	4.248	5.820	1.782	1.058	0.887	0.837
TOTAL DEPTH (cm)	2.220	2.166	2.010	1.992	2.205	7.416	10.791	14.782	4.526	2.686	2.252	2.125

ANNUAL SUMMARY:
Sum of Mean Daily Flow 290.195 cfs = 8.218 cms
Total Depth 21.720 in = 55.170 cm
Maximum Instantaneous Flow 4.327 cfs - 0.123 cms on May 8 at 03.75 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 3
WATERSHED AREA: 318 ACRES (128 HECTARES)

WATER YEAR 1973
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.361	0.360	0.367	0.367	0.367	0.488	0.582	0.893	0.410	0.323	0.266	0.273
2	0.363	0.378	0.378	0.372	0.365	0.480	0.569	0.847	0.399	0.319	0.267	0.264
3	0.358	0.375	0.387	0.369	0.363	0.473	1.222	0.858	0.391	0.315	0.274	0.264
4	0.358	0.426	0.370	0.368	0.361	0.467	0.670	0.926	0.389	0.311	0.271	0.263
5	0.352	0.412	0.351	0.368	0.363	0.468	0.751	0.896	0.381	0.310	0.267	0.260
6	0.348	0.376	0.355	0.368	0.363	0.463	0.766	0.877	0.375	0.306	0.266	0.257
7	0.345	0.370	0.359	0.368	0.352	0.461	0.736	0.852	0.374	0.305	0.263	0.350
8	0.339	0.375	0.352	0.369	0.352	0.456	0.725	0.879	0.371	0.301	0.269	0.285
9	0.354	0.366	0.347	0.370	0.351	0.463	0.737	0.815	0.361	0.297	0.263	0.273
10	0.382	0.363	0.349	0.370	0.355	0.471	0.758	0.766	0.351	0.289	0.268	0.268
11	0.378	0.364	0.352	0.365	0.355	0.456	0.834	0.719	0.346	0.290	0.262	0.266
12	0.335	0.362	0.348	0.366	0.354	0.450	0.964	0.677	0.346	0.295	0.256	0.265
13	0.329	0.360	0.341	0.495	0.356	0.451	1.223	0.646	0.347	0.294	0.252	0.264
14	0.327	0.358	0.336	0.462	0.356	0.452	1.201	0.621	0.417	0.293	0.252	0.269
15	0.336	0.358	0.331	0.422	0.354	0.458	1.062	0.591	0.384*	0.293	0.250	0.268
16	0.334	0.362	0.330	0.572	0.355	0.474	1.019	0.568	0.365	0.289	0.248	0.265
17	0.336	0.386	0.338	0.510	0.360	0.491	1.008	0.547	0.414	0.286	0.247	0.265
18	0.338	0.376	0.349	0.460	0.359	0.470	0.929	0.530	0.377	0.284	0.247	0.265
19	0.341	0.372	0.395	0.427	0.357	0.468	0.865	0.522	0.364	0.296	0.244	0.305
20	0.342	0.365	0.358	0.413	0.356	0.474	0.819	0.509	0.352	0.297	0.245	0.401
21	0.346	0.362	0.503	0.413	0.358	0.498	0.816	0.493	0.348	0.298	0.256	0.306
22	0.349	0.353	0.594	0.413	0.367	0.517	0.835	0.483	0.340	0.294	0.253	0.304
23	0.354	0.356	0.430	0.413	0.377	0.531	0.894	0.480	0.347	0.292	0.251	0.317
24	0.354	0.354	0.403	0.412	0.385	0.596	0.946	0.483*	0.343	0.288	0.253	0.392
25	0.361	0.361	0.378	0.408	0.392	0.691	0.965	0.498*	0.340	0.282	0.265	0.351
26	0.360	0.409	0.372	0.397	0.399	0.744	0.993	0.466	0.336	0.280	0.263	0.309
27	0.360	0.378	0.375	0.395	0.427	0.692	1.065	0.450	0.335	0.275	0.260	0.299
28	0.360	0.370	0.379	0.395	0.451	0.643	1.072	0.440	0.331*	0.271	0.259	0.294
29	0.357	0.366	0.371	0.395		0.619	1.004	0.434	0.335	0.268	0.259	0.289
30	0.356	0.362	0.368	0.385		0.605	0.943	0.416	0.328	0.266	0.260	0.291
31	0.357		0.366	0.373		0.601		0.421		0.270	0.276	

MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	10.869	11.131	11.634	12.581	10.309	16.072	26.972	19.605	10.898	9.078	8.033	8.740
TOTAL FLOW (cms days)	0.308	0.315	0.329	0.356	0.292	0.455	0.764	0.555	0.309	0.257	0.227	0.248
TOTAL DEPTH (in)	0.814	0.833	0.871	0.942	0.772	1.203	2.019	1.467	0.816	0.679	0.601	0.654
TOTAL DEPTH (cm)	2.066	2.116	2.212	2.392	1.960	3.056	5.128	3.727	2.072	1.726	1.527	1.662

ANNUAL SUMMARY:
Sum of Mean Daily Flow 155.923 cfs = 4.416 cms
Total Depth 11.671 in = 29.643 cm
Maximum Instantaneous Flow 1.300 cfs = 0.037 cms on April 13 at 21.75 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 3
WATERSHED AREA: 318 ACRES (128 HECTARES)

WATER YEAR 1974
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.289	0.395	0.439	0.405*	0.500	0.554	1.936	4.605	1.323	0.642	0.455	0.387
2	0.289	0.346	0.427	0.403*	0.490	0.505	1.751	4.667	1.233	0.626	0.461	0.386
3	0.288	0.330	0.421	0.407*	0.490	0.465	1.588	4.588	1.187	0.601	0.458	0.385
4	0.288	0.325	0.418	0.411*	0.489	0.456	1.467	4.607	1.194	0.591	0.453	0.381
5	0.285	0.342	0.413	0.412*	0.472	0.466	1.436	4.963	1.184	0.586	0.441	0.374
6	0.286	0.452	0.411	0.413*	0.466	0.459	1.594	5.157	1.117	0.583	0.477	0.368
7	0.364	0.402	0.445	0.414*	0.466	0.448	1.499	5.123	1.074	0.579	0.499	0.366
8	0.312	0.409	0.434	0.416*	0.465	0.448	1.567	5.174	1.015	0.596	0.469	0.367
9	0.303	0.479	0.422	0.416*	0.462	0.448	1.714	4.742	0.963	0.665	0.455	0.376
10	0.301	0.774	0.417	0.417*	0.462	0.463	1.691	4.165	0.920	0.666	0.448	0.381
11	0.301	0.854	0.422*	0.418*	0.462	0.474	1.750	3.613	0.904	0.649	0.444	0.383
12	0.304	1.107	0.427*	0.418*	0.459	0.526	1.850	3.260	0.891	0.585	0.439	0.388
13	0.301	0.770	0.425*	0.418*	0.456	0.545	1.804	2.875	0.878	0.564	0.436	0.378
14	0.300	0.610	0.423*	0.430*	0.454	0.537	2.059	2.576	0.855	0.554	0.439	0.367
15	0.299	0.500	0.423*	0.545*	0.455	0.546	2.468	2.301	0.845	0.554	0.431	0.365
16	0.297	0.498	0.429*	0.946*	0.458	0.640	2.962	2.084	0.812	0.540	0.425	0.364
17	0.295	0.502	0.439*	1.370*	0.450	1.134	3.722	1.980	0.786	0.526	0.422	0.364
18	0.293	0.486	0.442*	1.285*	0.447	1.255	4.716	1.883	0.765	0.516	0.421	0.369
19	0.292	0.446	0.438*	1.037*	0.449	1.170	5.242	1.798	0.743	0.514	0.449	0.360
20	0.298	0.425	0.436*	0.914*	0.435	1.051	5.113	1.768	0.772	0.508	0.488	0.358
21	0.302	0.409	0.436*	0.803*	0.427	0.992	4.998	1.722	0.732	0.500	0.444	0.362
22	0.301	0.392	0.436*	0.733*	0.425	1.006	5.062	1.694	0.715	0.495	0.437	0.360
23	0.340	0.385	0.436*	0.684	0.422	0.963	6.232	1.725	0.703	0.489	0.428	0.353
24	0.346	0.378	0.434*	0.645	0.425	0.981	7.339*	1.819	0.683	0.483	0.427	0.346
25	0.370	0.375	0.431*	0.600	0.427	1.082	6.988	1.858	0.668	0.482	0.415	0.347
26	0.330	0.393	0.429*	0.566	0.430	1.371	5.884	1.878	0.659	0.481	0.406	0.350
27	0.323	0.399	0.425*	0.554	0.427	1.646	4.659	1.850	0.653	0.483	0.408	0.341
28	0.323	0.405	0.422*	0.542	0.448	2.030	3.940	1.748	0.661	0.474	0.397	0.340
29	0.323	0.409	0.420*	0.531		1.751	3.818	1.660	0.663	0.469	0.391	0.346
30	0.316	0.417	0.414*	0.517		2.021	4.203	1.538	0.651	0.471	0.391	0.343
31	0.412		0.409*	0.512		2.051		1.434		0.460	0.388	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	9.671	14.413	13.246	18.585	12.716	28.486	101.051	90.854	26.248	16.930	13.541	10.955
TOTAL FLOW (cms days)	0.274	0.408	0.375	0.526	0.360	0.807	2.862	2.573	0.743	0.479	0.383	0.310
TOTAL DEPTH (in)	0.724	1.079	0.991	1.391	0.952	2.132	7.563	6.800	1.965	1.267	1.014	0.820
TOTAL DEPTH (cm)	1.839	2.740	2.518	3.533	2.418	5.415	19.211	17.273	4.990	3.219	2.574	2.083

ANNUAL SUMMARY:
Sum of Mean Daily Flow 356.695 cfs = 10.102 cms
Total Depth 26.698 in = 67.813 cm
Maximum Instantaneous Flow 8.211 cfs = 0.233 cms on April 24 at 17.50 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 3
WATERSHED AREA: 318 ACRES (128 HECTARES)

WATER YEAR 1975
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.350	0.384	0.381	0.367	0.405	0.425	0.414	0.813	1.428	0.516	0.393	0.336
2	0.363	0.385	0.380	0.368	0.395	0.471	0.414	1.082	1.409	0.508	0.392	0.333
3	0.369	0.383	0.388	0.369	0.388	0.450	0.416	1.538	1.304	0.495	0.389	0.330
4	0.371	0.384	0.423	0.375	0.390	0.453	0.407	1.396	1.154	0.492	0.384	0.331
5	0.377	0.385	0.400	0.368	0.385	0.459	0.404	1.140	1.045	0.478	0.372	0.330
6	0.378	0.385	0.393	0.369	0.389	0.458	0.399	0.991	0.946	0.470	0.370	0.325
7	0.374	0.445	0.389	0.365	0.397	0.481	0.398	0.967	0.879	0.457	0.377	0.329
8	0.371	0.432	0.380	0.369	0.389	0.535	0.394	1.126	0.823	0.446	0.374	0.326
9	0.396	0.397	0.374	0.359	0.391	0.533	0.395	1.482	0.785	0.431	0.370	0.325
10	0.397	0.400	0.374	0.357	0.393	0.503	0.397	2.441	0.752	0.434	0.368	0.327
11	0.385	0.392	0.375	0.354	0.393	0.482	0.436	3.220	0.744	0.453	0.361	0.329
12	0.380	0.393	0.371	0.356	0.399	0.475	0.496	3.401	0.708	0.452	0.360	0.325
13	0.379	0.393	0.371	0.359	0.410	0.472	0.574	4.002	0.685	0.460	0.358	0.326
14	0.376	0.392	0.368	0.359	0.402	0.476	0.614	5.167	0.661	0.444	0.362	0.410
15	0.375	0.389	0.369	0.345	0.393	0.479	0.582	5.740*	0.639	0.436	0.353	0.340
16	0.370	0.389	0.375	0.360	0.392	0.478	0.568	5.309	0.621	0.430	0.356	0.326
17	0.368	0.392	0.378	0.363	0.390	0.467	0.595	4.706	0.743	0.442	0.371	0.326
18	0.371	0.425	0.374	0.390	0.390	0.536	0.708	4.209	0.846	0.429	0.427	0.323
19	0.369	0.412	0.376	0.375	0.394	0.571	0.763	3.659	0.748	0.420	0.421	0.322
20	0.373	0.414	0.386	0.376	0.393	0.516	0.812	2.964	0.733	0.411	0.397	0.318
21	0.415	0.429	0.396	0.376	0.389	0.495	0.883	2.564	0.668	0.403	0.373	0.314
22	0.400	0.425	0.384	0.375	0.388	0.486	1.033	2.304	0.633	0.405	0.411	0.317
23	0.400	0.408	0.378	0.378	0.396	0.476	1.086	2.171	0.618	0.393	0.472	0.312
24	0.397	0.408	0.376	0.385	0.398	0.474	0.938	1.988	0.621	0.394	0.398	0.309
25	0.385	0.408	0.376	0.533	0.397	0.472	0.985	1.794	0.644	0.391	0.359	0.305
26	0.381	0.402	0.370	0.450	0.394	0.446	0.882	1.659	0.604	0.391	0.346	0.305
27	0.379	0.402	0.384	0.412	0.388	0.429	0.837	1.620	0.574	0.392	0.338	0.314
28	0.382	0.392	0.373	0.407	0.394	0.430	0.769	1.580	0.560	0.388	0.356	0.318
29	0.380	0.390	0.369	0.404		0.438	0.737	1.555	0.547	0.403	0.342	0.324
30	0.379	0.382	0.370	0.397		0.439	0.737	1.543	0.528	0.409	0.335	0.325
31	0.381		0.363	0.404		0.420		1.509		0.397	0.329	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	11.774	12.014	11.765	11.824	11.022	14.724	19.075	75.639	23.650	13.474	11.612	9.782
TOTAL FLOW (cms days)	0.333	0.340	0.333	0.335	0.312	0.417	0.540	2.142	0.670	0.382	0.329	0.277
TOTAL DEPTH (in)	0.881	0.899	0.881	0.885	0.825	1.102	1.428	5.661	1.770	1.008	0.869	0.732
TOTAL DEPTH (cm)	2.238	2.284	2.237	2.248	2.095	2.799	3.626	14.380	4.496	2.562	2.208	1.860

ANNUAL SUMMARY:
Sum of Mean Daily Flow 226.357 cfs = 6.410 cms
Total Depth 16.942 in = 43.033 cm
Maximum Instantaneous Flow 6.545 cfs = 0.185 cms on May 14 at 17.25 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 3
WATERSHED AREA: 318 ACRES (128 HECTARES)

WATER YEAR 1976
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.292	0.399	1.112*	0.375*	0.487*	0.416	0.697	2.846	0.770	0.483	0.419	0.369
2	0.305	0.399	0.836*	0.377*	0.514*	0.410	0.680	3.361	0.736	0.472	0.407	0.369
3	0.311	0.410	0.657*	0.376*	0.521*	0.410	0.753	3.645	0.716	0.465	0.400	0.365
4	0.316	0.409	0.685*	0.376*	0.508*	0.416	1.020	3.705	0.716	0.462	0.402	0.371
5	0.312	0.405	0.909*	0.375*	0.479*	0.418	1.505	3.522	0.700	0.457	0.399	0.369
6	0.400	0.409	0.696*	0.378*	0.447*	0.422	1.758	3.290	0.685	0.448	0.386	0.388
7	0.467	0.454	1.140*	0.381*	0.421*	0.433	1.805	3.353	0.672	0.449	0.383	0.378
8	0.350	0.418	1.356*	0.383*	0.407*	0.436	2.273	3.458	0.663	0.443	0.406	0.377
9	0.337	0.403	1.240*	0.377*	0.402*	0.444	2.635	3.423	0.653	0.438	0.393	0.372
10	0.341	0.405	1.007*	0.374*	0.390*	0.471	2.528	3.277	0.682	0.428	0.380	0.369
11	0.413	0.390	0.809*	0.368*	0.383*	0.485	2.645	3.085	0.760	0.428	0.381	0.431
12	0.409	0.388	0.690*	0.363*	0.380*	0.470	2.694	2.702	0.706	0.429	0.381	0.390
13	0.375	0.391	0.630*	0.358*	0.377*	0.468	2.555	2.468	0.692	0.421	0.376	0.378
14	0.356	0.391	0.589*	0.354*	0.382*	0.469	2.521	2.296	0.654	0.412	0.377	0.377
15	0.348	0.450	0.573*	0.349*	0.385*	0.463	2.370	2.038	0.630	0.411	0.377	0.377
16	0.342	0.473	0.517*	0.345*	0.386*	0.467	2.038	1.862	0.647	0.409	0.462	0.411
17	0.340	0.441	0.479*	0.343*	0.387*	0.479	1.874	1.668	0.622	0.439	0.423	0.405
18	0.335	0.419	0.473*	0.360*	0.386*	0.495	1.745	1.541	0.603	0.590	0.403	0.404
19	0.342	0.401	0.465	0.361*	0.385*	0.483	1.663	1.424	0.587	0.452	0.409	0.389
20	0.359	0.385	0.463	0.373*	0.378*	0.477	1.672	1.293	0.582	0.424	0.393	0.384
21	0.427	0.371	0.461	0.367*	0.376*	0.477	1.645	1.198	0.616	0.413	0.382	0.375
22	0.401	0.365	0.452	0.368*	0.373*	0.483	1.621	1.114	0.584	0.400	0.378	0.382
23	0.382	0.366	0.431	0.368*	0.375*	0.493	1.610	1.038	0.561	0.393	0.394	0.380
24	0.375	0.363*	0.425	0.368*	0.393*	0.506	1.880	1.003	0.551	0.419	0.417	0.372
25	0.383	0.347*	0.418	0.365*	0.412	0.501	2.240	0.949	0.539	0.402	0.398	0.367
26	0.427	0.346*	0.422	0.359*	0.426	0.499	2.016	0.907	0.529	0.398	0.398	0.369
27	0.398	0.346*	0.409*	0.356*	0.435	0.494	1.914	0.877	0.519	0.389	0.397	0.365
28	0.389	0.338*	0.394*	0.355*	0.426	0.491	1.881	0.878	0.504	0.393	0.382	0.356
29	0.398	0.323*	0.394*	0.379*	0.418	0.497	2.029	0.831	0.488	0.413	0.378	0.349
30	0.409	0.314*	0.392*	0.414*		0.523	2.335	0.801	0.488	0.407	0.374	0.346
31	0.408		0.381*	0.452*		0.590		0.858		0.404	0.372	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	11.446	11.719	19.902	11.495	12.038	14.583	56.603	64.710	18.857	13.393	12.228	11.333
TOTAL FLOW (cms days)	0.324	0.332	0.564	0.326	0.341	0.413	1.603	1.833	0.534	0.379	0.346	0.321
TOTAL DEPTH (in)	0.857	0.877	1.490	0.860	0.901	1.092	4.237	4.843	1.411	1.002	0.915	0.848
TOTAL DEPTH (cm)	2.176	2.228	3.784	2.185	2.289	2.772	10.761	12.302	3.585	2.546	2.325	2.155

ANNUAL SUMMARY:
Sum of Mean Daily Flow 258.308 cfs = 7.315 cms
Total Depth 19.334 in = 49.108 cm
Maximum Instantaneous Flow 3.843 cfs = 0.109 cms on May 4 at 01.00 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 3
WATERSHED AREA: 318 ACRES (128 HECTARES)

WATER YEAR 1977
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.336	0.350	0.344	0.308	0.311	0.368	0.359	0.350	0.359	0.296	0.256	0.277
2	0.358	0.351	0.344	0.306	0.309	0.365	0.355	0.361	0.354	0.307	0.261	0.272
3	0.360	0.349	0.347	0.316	0.306	0.367	0.359	0.380	0.348	0.317	0.259	0.265
4	0.360	0.346	0.345	0.311	0.308	0.367	0.415	0.376	0.341	0.320	0.259	0.263
5	0.357	0.344	0.332	0.312	0.305	0.371	0.461	0.371	0.335	0.301	0.267	0.260
6	0.354	0.344	0.326	0.310	0.311	0.378	0.482	0.380	0.328	0.296	0.269	0.258
7	0.349	0.343	0.328	0.305	0.316	0.381	0.521	0.388	0.509	0.291	0.271	0.254
8	0.349	0.340	0.327	0.299	0.314	0.386	0.541	0.380	0.413	0.284	0.302	0.258
9	0.352	0.339	0.319	0.299	0.316	0.393	0.508	0.377	0.370	0.279	0.274	0.259
10	0.353	0.343	0.311	0.304	0.315	0.372	0.467	0.427	0.508	0.284	0.268	0.258
11	0.353	0.343	0.307	0.306	0.313	0.370	0.448	0.383	0.471	0.281	0.267	0.258
12	0.352	0.344	0.310	0.312	0.316	0.378	0.439	0.366	0.431	0.283	0.266	0.254
13	0.351	0.346	0.311	0.308	0.319	0.375	0.441	0.352	0.397	0.280	0.266	0.257
14	0.351	0.343	0.312	0.309	0.314	0.372	0.427	0.348	0.391	0.280	0.267	0.259
15	0.351	0.344	0.309	0.304	0.314	0.366	0.411	0.347	0.366	0.285	0.268	0.269
16	0.346	0.349	0.310	0.304	0.324	0.371	0.411	0.383	0.347	0.281	0.268	0.295
17	0.349	0.349	0.311	0.305	0.325	0.368	0.404	0.383	0.340	0.283	0.264	0.315
18	0.348	0.348	0.311	0.304	0.326	0.361	0.390	0.378	0.337	0.283	0.261	0.276
19	0.351	0.348	0.308	0.306	0.327	0.360	0.382	0.371	0.340	0.285	0.261	0.282
20	0.352	0.352	0.309	0.306	0.343	0.355	0.376	0.358	0.344	0.280	0.258	0.314
21	0.353	0.355	0.308	0.307	0.351	0.355	0.362	0.351	0.334	0.284	0.264	0.298
22	0.351	0.356	0.310	0.305	0.350	0.373	0.364	0.351	0.332	0.296	0.264	0.287
23	0.352	0.359	0.309	0.303	0.349	0.389	0.368	0.470	0.326	0.295	0.263	0.284
24	0.350	0.362	0.311	0.300	0.345	0.383	0.375	0.481	0.320	0.372	0.300	0.404
25	0.358	0.362	0.304	0.296	0.352	0.373	0.374	0.461	0.315	0.305	0.322	0.323
26	0.359	0.357	0.309	0.295	0.352	0.374	0.370	0.454	0.324	0.292	0.360	0.309
27	0.354	0.348	0.304	0.306	0.356	0.372	0.367	0.454	0.327	0.287	0.311	0.299
28	0.353	0.350	0.303	0.310	0.371	0.369	0.359	0.427	0.319	0.280	0.290	0.306
29	0.353	0.351	0.303	0.312		0.364	0.360	0.408	0.301	0.273	0.283	0.395
30	0.353	0.349	0.304	0.315		0.374	0.365	0.388	0.294	0.269	0.300	0.342
31	0.351		0.305	0.314		0.367		0.373		0.262	0.289	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	10.918	10.463	9.791	9.498	9.159	11.513	12.262	12.075	10.821	9.011	8.576	8.648
TOTAL FLOW (cms days)	0.309	0.296	0.277	0.269	0.259	0.326	0.347	0.342	0.306	0.255	0.243	0.245
TOTAL DEPTH (in)	0.817	0.783	0.733	0.711	0.686	0.862	0.918	0.904	0.810	0.674	0.642	0.647
TOTAL DEPTH (cm)	2.076	1.989	1.861	1.806	1.741	2.189	2.331	2.296	2.057	1.713	1.631	1.644

ANNUAL SUMMARY:
Sum of Mean Daily Flow 122.735 cfs = 3.476 cms
Total Depth 9.186 in = 23.334 cm
Maximum Instantaneous Flow 3.325 cfs = 0.094 cms on June 7 at 21.00 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 3
WATERSHED AREA: 318 ACRES (128 HECTARES)

WATER YEAR 1978
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.323	0.310	0.323	0.324	0.324	0.395	3.975	2.079	0.576	0.400	0.347	0.300
2	0.307	0.324	0.405	0.324	0.325	0.401	3.013	2.030	0.562	0.394	0.344	0.295
3	0.301	0.312	0.454	0.325	0.336	0.402	2.402	1.939	0.563	0.404	0.343	0.294
4	0.311	0.311	0.404	0.325	0.333	0.407	2.070	1.789	0.543	0.409	0.338	0.298
5	0.307	0.353	0.370	0.324	0.339	0.421	1.812	1.605	0.527	0.400	0.330	0.307
6	0.304	0.337	0.358	0.325	0.372	0.448	1.661	1.478	0.513	0.390	0.320	0.376
7	0.303	0.321	0.347	0.325	0.365	0.453	1.575	1.376	0.496	0.387	0.316	0.391
8	0.303	0.310	0.335	0.326	0.356	0.509	1.520	1.317	0.485	0.378	0.309	0.375
9	0.303	0.309	0.328	0.326	0.351	0.616	1.570	1.359	0.510	0.376	0.307	0.315
10	0.300	0.309	0.324	0.325	0.346	0.645	1.733	1.419	0.568	0.381	0.313	0.342
11	0.296	0.308	0.328	0.325	0.347	0.680	1.906	1.479	0.536	0.393	0.316	0.281
12	0.296	0.308	0.324	0.324	0.343	0.685	1.862	1.420	0.509	0.392	0.313	0.292
13	0.295	0.309	0.358	0.324	0.336	0.626	1.770	1.371	0.491	0.389	0.403	0.294
14	0.294	0.310	0.907	0.324	0.334	0.581	1.707	1.340	0.478	0.400	0.351	0.293
15	0.294	0.394	1.845	0.324	0.335	0.547	1.790	1.360	0.479	0.402	0.335	0.288
16	0.295	0.355	0.900	0.325	0.336	0.552	2.004	1.259	0.470	0.402	0.343	0.294
17	0.297	0.330	0.636	0.325	0.331	0.635	1.822	1.152	0.469	0.402	0.329	0.303
18	0.298	0.316	0.498	0.326	0.331	0.861	1.726	1.085	0.482	0.395	0.325	0.296
19	0.298	0.311	0.482	0.327	0.343	1.128	1.710	1.024	0.464	0.385	0.323	0.290
20	0.296	0.315	0.434	0.327	0.353	1.321	1.757	0.975	0.441	0.386	0.326	0.293
21	0.294	0.308	0.428	0.327	0.360	1.535	1.642	0.929	0.436	0.387	0.320	0.300
22	0.296	0.324	0.379	0.325	0.376	1.937	1.513	0.901	0.434	0.387	0.337	0.306
23	0.296	0.300	0.324	0.324	0.387	2.288	1.454	0.859	0.429	0.382	0.332	0.317
24	0.291	0.295	0.325	0.324	0.400	2.019	1.464	0.813	0.436	0.373	0.326	0.325
25	0.295	0.398	0.326	0.327	0.405	1.797	1.608	0.775	0.506	0.369	0.321	0.327
26	0.319	0.509	0.326	0.329	0.401	2.042	2.094	0.744	0.462	0.365	0.321	0.325
27	0.304	0.373	0.325	0.324	0.397	2.568	2.434	0.726	0.449	0.360	0.316	0.306
28	0.305	0.344	0.324	0.326	0.384	3.034	2.352	0.686	0.434	0.363	0.311	0.305
29	0.306	0.339	0.324	0.328		3.641	2.220	0.660	0.430	0.360	0.310	0.299
30	0.328	0.328	0.324	0.323		4.261	2.126	0.633	0.440	0.356	0.309	0.298
31	0.314		0.324	0.324		4.123		0.595		0.351	0.309	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	9.367	9.972	14.089	10.080	9.946	41.557	58.292	37.178	14.619	11.918	10.142	9.326
TOTAL FLOW (cms days)	0.265	0.282	0.399	0.285	0.282	1.177	1.651	1.053	0.414	0.338	0.287	0.264
TOTAL DEPTH (in)	0.701	0.746	1.055	0.754	0.744	3.110	4.363	2.783	1.094	0.892	0.759	0.698
TOTAL DEPTH (cm)	1.781	1.896	2.679	1.916	1.891	7.901	11.082	7.068	2.779	2.266	1.928	1.773

ANNUAL SUMMARY:
Sum of Mean Daily Flow 236.485 cfs = 6.697 cms
Total Depth 17.700 in = 44.959 cm
Maximum Instantaneous Flow 4.439 cfs = 0.126 cms on March 30 at 19.00 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 3
WATERSHED AREA: 318 ACRES (128 HECTARES)

WATER YEAR 1979
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.310	0.320	0.334	0.314	0.317	0.303*	0.527*	1.080*	0.524*	0.300*	0.251	0.271
2	0.303	0.319	0.324	0.320	0.320	0.390*	0.483*	1.044*	0.525*	0.299*	0.260	0.262
3	0.303	0.314	0.319	0.327	0.321	0.347*	0.450*	1.021*	0.529*	0.297*	0.269	0.257
4	0.302	0.306	0.443	0.329	0.321	0.306*	0.471*	1.013*	0.531*	0.296*	0.270	0.259
5	0.306	0.306	0.350	0.317	0.321	0.285*	0.595*	0.997*	0.525*	0.296*	0.269	0.253
6	0.307	0.300	0.322	0.316	0.321	0.283*	0.743*	0.962*	0.508*	0.295*	0.270	0.252
7	0.304	0.300	0.309	0.317	0.321	0.296*	0.748*	0.937*	0.510*	0.294*	0.273	0.252
8	0.299	0.316	0.308	0.317	0.315	0.327*	0.852*	0.924*	0.511*	0.293*	0.293	0.251
9	0.297	0.313	0.315	0.316	0.313	0.419*	0.966*	0.898*	0.503*	0.292*	0.277	0.251
10	0.298	0.299	0.321	0.319	0.312	0.593*	0.845*	0.845*	0.486*	0.292*	0.265	0.249
11	0.298	0.298	0.332	0.353	0.313	0.645*	0.731*	0.883*	0.464*	0.290*	0.262	0.248
12	0.300	0.302	0.324	0.344	0.315	0.700*	0.652*	0.904*	0.438*	0.289*	0.274	0.249
13	0.300	0.300	0.320	0.319	0.317	0.669*	0.617*	0.857*	0.425*	0.288*	0.349	0.247
14	0.301	0.299	0.314	0.316	0.317	0.650*	0.596*	0.819*	0.416*	0.287*	0.318	0.247
15	0.299	0.298	0.312	0.317	0.316	0.639*	0.724*	0.774*	0.400*	0.287*	0.298	0.248
16	0.298	0.299	0.307	0.317	0.315	0.631*	0.880*	0.748*	0.388*	0.286*	0.276	0.247
17	0.299	0.304	0.312	0.314	0.314	0.624*	1.158*	0.701*	0.417*	0.285*	0.293	0.245
18	0.298	0.305	0.325	0.316	0.316	0.619*	0.999*	0.665*	0.453*	0.284*	0.306	0.248
19	0.297	0.310	0.320	0.317	0.320	0.615*	0.863*	0.630*	0.464*	0.283*	0.301	0.250
20	0.300	0.313	0.320	0.316	0.325	0.608*	0.794*	0.594*	0.437*	0.283*	0.282	0.250
21	0.299	0.310	0.319	0.320	0.326	0.600*	0.793*	0.574*	0.369*	0.281*	0.283	0.250
22	0.299	0.315	0.329	0.321	0.327	0.594*	0.821*	0.567*	0.421*	0.280*	0.280	0.250
23	0.298	0.311	0.327	0.319	0.334*	0.623*	0.885*	0.561*	0.370*	0.279*	0.309	0.251
24	0.299	0.307	0.328	0.322	0.341*	0.665*	0.910*	0.561*	0.318*	0.278*	0.291	0.256
25	0.302	0.305	0.322	0.321	0.341*	0.684*	0.891*	0.560*	0.315*	0.270	0.268	0.285
26	0.304	0.304	0.318	0.319	0.342*	0.680*	0.926*	0.544*	0.311*	0.263	0.265	0.294
27	0.302	0.305	0.314	0.318	0.342*	0.755*	0.976*	0.542*	0.309*	0.266	0.280	0.277
28	0.304	0.310	0.314	0.317	0.328*	0.810*	1.050*	0.540*	0.305*	0.263	0.276	0.271
29	0.305	0.318	0.306	0.318		0.758*	1.096*	0.530*	0.302*	0.258	0.268	0.270
30	0.305	0.332	0.304	0.318		0.648*	1.113*	0.532*	0.301*	0.254	0.275	0.270
31	0.317		0.310	0.317		0.575*		0.526*		0.252	0.283	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	9.351	9.234	10.019	9.929	9.030	17.340	24.154	23.331	12.776	8.758	8.735	7.708
TOTAL FLOW (cms days)	0.265	0.262	0.284	0.281	0.256	0.491	0.684	0.661	0.362	0.248	0.247	0.218
TOTAL DEPTH (in)	0.700	0.691	0.750	0.743	0.676	1.298	1.808	1.746	0.956	0.656	0.654	0.577
TOTAL DEPTH (cm)	1.778	1.755	1.905	1.888	1.717	3.297	4.592	4.436	2.429	1.665	1.661	1.465

ANNUAL SUMMARY:
Sum of Mean Daily Flow 150.366 cfs = 4.258 cms
Total Depth 11.255 in = 28.587 cm
Maximum Instantaneous Flow 1.399 cfs = 0.040 cms on April 17 at 04.45 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 3
WATERSHED AREA: 318 ACRES (128 HECTARES)

WATER YEAR 1980
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.268	0.342	0.311	0.322	0.317	0.616	0.470	2.158	0.958	0.514	0.380	0.350
2	0.270	0.341	0.320	0.318	0.316	0.607	0.472	2.030	0.978	0.526	0.368	0.386
3	0.277	0.341	0.369	0.317	0.328	0.585	0.467	1.877	0.932	0.526	0.369	0.366
4	0.274	0.350	0.342	0.317*	0.309	0.576	0.473	1.708	0.896	0.502	0.366	0.358
5	0.273	0.356	0.331	0.318*	0.299	0.550	0.524	1.562	0.982	0.489	0.359	0.354
6	0.275	0.349	0.329	0.318	0.299	0.518	0.531	1.673	0.954	0.483	0.353	0.351
7	0.278	0.345	0.329	0.314	0.297	0.492	0.511	1.602	0.923	0.480	0.349	0.341
8	0.277	0.344	0.334	0.316	0.295	0.476	0.508	1.475	0.880	0.475	0.347	0.343
9	0.275	0.343	0.333	0.318*	0.294	0.463	0.554	1.487	0.842	0.472	0.344	0.349
10	0.275	0.342	0.343	0.321*	0.293	0.470	0.547	1.458	0.801	0.454	0.340	0.440
11	0.278	0.338	0.326	0.324	0.294	0.460	0.575	1.391	0.772	0.442	0.336	0.455
12	0.277	0.335	0.327	0.381	0.294	0.445	0.700	1.241	0.808*	0.440	0.335	0.367
13	0.277	0.333	0.325	0.513	0.293	0.439	1.022	1.154	0.741*	0.433	0.339	0.445
14	0.275	0.329	0.325	0.660	0.292	0.452	1.385	1.078	0.761*	0.444	0.341	0.401
15	0.386	0.328	0.325	0.574	0.292	0.427	1.674	1.080	0.741	0.447	0.429	0.372
16	0.334	0.327	0.323	0.467	0.296	0.414	1.855	1.128	0.701	0.441	0.348	0.357
17	0.339	0.333	0.322	0.423	0.312	0.410	2.338	1.022	0.672	0.430	0.329	0.354
18	0.386	0.333	0.323	0.394	0.413	0.418	3.078	0.951	0.651	0.426	0.355	0.398
19	0.475	0.329	0.323	0.381	0.499	0.413	3.884	0.896	0.630	0.420	0.360	0.387
20	0.369	0.326	0.323	0.373	0.490	0.416	4.349	0.851	0.611	0.416	0.361	0.401
21	0.356	0.325	0.323	0.367	0.459	0.416	4.468	0.820	0.593	0.416	0.360	0.398
22	0.364	0.325	0.321	0.364	0.427	0.430	4.394	0.827	0.586	0.416	0.359	0.380
23	0.395	0.329	0.320	0.361	0.407	0.442	4.421	0.851	0.600	0.408	0.352	0.376
24	0.367	0.330	0.320*	0.358	0.392	0.443	4.318	0.855	0.592	0.401	0.347	0.374
25	0.398	0.322	0.321*	0.354	0.392	0.450	3.852	0.970	0.563	0.399	0.346	0.369
26	0.391	0.321	0.320	0.350	0.406	0.464	3.343	1.042	0.543	0.392	0.350	0.365
27	0.358	0.317	0.317	0.343	0.470	0.470	3.232	1.049	0.531	0.395	0.352	0.361
28	0.357	0.312	0.314	0.331	0.585	0.470	3.218	1.031	0.517	0.392	0.349	0.352
29	0.350	0.309	0.313	0.327	0.596	0.475	2.952	1.029	0.503	0.385	0.346	0.352
30	0.346	0.310	0.312	0.322		0.473	2.427	0.986	0.500	0.380	0.348	0.353
31	0.345		0.317	0.317		0.472		0.926		0.386	0.351	
MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	10.165	9.965	10.081	11.464	10.655	14.652	62.542	38.210	21.760	13.629	10.966	11.253
TOTAL FLOW (cms days)	0.288	0.282	0.285	0.325	0.302	0.415	1.771	1.082	0.616	0.386	0.311	0.319
TOTAL DEPTH (in)	0.761	0.746	0.755	0.858	0.797	1.097	4.681	2.860	1.629	1.020	0.821	0.842
TOTAL DEPTH (cm)	1.933	1.895	1.916	2.180	2.026	2.786	11.890	7.264	4.137	2.591	2.085	2.139

ANNUAL SUMMARY:
Sum of Mean Daily Flow 225.342 cfs = 6.382 cms
Total Depth 16.866 in = 42.841 cm
Maximum Instantaneous Flow 5.049 cfs = 0.143 cms on April 20 at 20.74 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 3
WATERSHED AREA: 318 ACRES (128 HECTARES)

WATER YEAR 1981
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.342	0.363*	0.367	0.677	0.435	0.777	1.023	1.306*	0.651	0.505	0.427*	0.344
2	0.344	0.361*	0.424	0.637	0.434	0.794	1.004	1.242*	0.663	0.496	0.412*	0.347
3	0.343	0.360*	0.551	0.600	0.432	0.799	0.992	1.186*	0.646	0.493	0.403*	0.343
4	0.342	0.357*	0.607	0.560	0.434	0.794	0.957	1.130*	0.626	0.489	0.396*	0.343
5	0.339	0.351*	0.484	0.540	0.432	0.776	0.956	1.073*	0.616	0.486	0.386*	0.342
6	0.342	0.439	0.445	0.541	0.433	0.755	0.949	1.017	0.617	0.580	0.387*	0.344
7	0.343	0.554	0.419	0.528	0.427	0.744	0.931	0.978	0.651	0.536	0.389*	0.340
8	0.336	0.419	0.407	0.517	0.424	0.742	0.909	0.918	0.745	0.501	0.392*	0.338
9	0.338*	0.380	0.399	0.506	0.423	0.749	0.908	0.880	0.701	0.487	0.397*	0.338
10	0.337*	0.374	0.397	0.498	0.411	0.761	0.887	0.896	0.665	0.477	0.401*	0.336
11	0.336*	0.373	0.398	0.491	0.409	0.763	0.881	0.868	0.633	0.469	0.400*	0.335
12	0.435*	0.375	0.398	0.479	0.413	0.778	0.863	0.830	0.653	0.459	0.395*	0.335
13	0.401*	0.370	0.396	0.472	0.432	0.792	0.845	0.785	0.646	0.456	0.372*	0.333
14	0.389*	0.364	0.395	0.459	0.547	0.804	0.868	0.777	0.636	0.452	0.358	0.331
15	0.372	0.359	0.395	0.450	0.483	0.816	0.939	0.839	0.619	0.449	0.353	0.331
16	0.364	0.357	0.397	0.449	0.707	0.842	1.016	0.768	0.624	0.435	0.345	0.331
17	0.363	0.356	0.398	0.449	0.806	0.820	1.079	0.730	0.621	0.429	0.340	0.328
18	0.360	0.353	0.396	0.450	0.787	0.794	1.199	0.697	0.606	0.426	0.343	0.329
19	0.357	0.353	0.392	0.449	1.094	0.777	1.598	0.704	0.603	0.431*	0.344	0.333
20	0.355	0.354	0.392	0.448	1.169	0.803	2.513	0.717	0.588	0.438*	0.362	0.339
21	0.358	0.361	0.432	0.443	1.002	0.801	2.449	0.720	0.575	0.430*	0.344	0.340
22	0.354	0.368	0.628	0.442	0.904	0.829	2.134	0.704	0.562	0.428*	0.343	0.341
23	0.353	0.363	0.527	0.476	0.859	0.831	1.874	0.692	0.553	0.428*	0.341	0.343
24	0.355	0.357	0.489	0.474	0.847	0.819*	1.876	0.694	0.542	0.432*	0.339	0.353
25	0.370	0.357	0.683	0.454	0.856	0.859*	1.836	0.797	0.536	0.435*	0.339	0.385
26	0.391	0.358	1.717	0.452	0.827	0.943*	1.842	0.766	0.526	0.438*	0.337	0.386
27	0.369	0.357	1.502	0.451	0.794	0.962*	1.733	0.725	0.520	0.443*	0.336	0.385
28	0.364	0.361	1.253	0.452	0.781	0.980	1.604	0.697	0.516	0.448*	0.339	0.408
29	0.365	0.369	0.952	0.450		1.034	1.508	0.676	0.509	0.450*	0.340	0.377
30	0.365	0.370	0.789	0.452		1.014	1.389	0.723	0.505	0.449*	0.343	0.367
31	0.365		0.705	0.438		0.999		0.679		0.445*	0.344	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	11.148	11.192	18.133	15.182	18.004	25.749	39.560	26.211	18.151	14.321	11.349	10.427
TOTAL FLOW (cms days)	0.316	0.317	0.514	0.430	0.510	0.729	1.120	0.742	0.514	0.406	0.321	0.295
TOTAL DEPTH (in)	0.834	0.838	1.357	1.136	1.348	1.927	2.961	1.962	1.359	1.072	0.849	0.780
TOTAL DEPTH (cm)	2.119	2.128	3.447	2.886	3.423	4.895	7.521	4.983	3.451	2.723	2.158	1.982

ANNUAL SUMMARY:
Sum of Mean Daily Flow 219.427 cfs = 6.214 cms
Total Depth 16.424 in = 41.716 cm
Maximum Instantaneous Flow 2.626 cfs = 0.074 cms on April 21 at 03.93 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 3
WATERSHED AREA: 318 ACRES (128 HECTARES)

WATER YEAR 1982
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.365	0.361	0.381*	0.418	0.364	0.762	0.865	5.936	1.504	0.728	0.496*	0.413*
2	0.364	0.342*	0.391*	0.406	0.366	0.826	0.835	7.465	1.387	0.726	0.496*	0.403*
3	0.367	0.273*	0.384*	0.406	0.366	0.799	0.826	7.878	1.274	0.723	0.490*	0.402*
4	0.369	0.268*	0.406	0.404	0.360	0.773	0.795	6.618	1.216	0.714	0.484*	0.398*
5	0.368	0.266*	0.408	0.395	0.351	0.739	0.773	5.478	1.203	0.711	0.480*	0.394*
6	0.367	0.262*	0.459	0.386	0.348	0.722	0.762	5.085	1.139	0.686	0.467*	0.391*
7	0.414	0.260*	0.454	0.376	0.345	0.721	0.746	5.009	1.090	0.713	0.454*	0.387*
8	0.374	0.260*	0.451	0.371	0.338	0.726	0.730	4.698	1.049*	0.724	0.460*	0.382*
9	0.371	0.258*	0.456	0.364	0.336	0.720	0.722	4.421	1.028*	0.687	0.481*	0.373*
10	0.425	0.255*	0.476	0.363	0.329	0.731	0.747	4.325	1.031*	0.653	0.482*	0.364*
11	0.427	0.255*	0.469	0.362	0.324	0.801	1.246	4.152	1.026*	0.645	0.487*	0.361*
12	0.383	0.368*	0.455	0.356	0.317	0.825	1.607	3.884	1.075*	0.642	0.492*	0.405*
13	0.373	0.476*	0.449	0.341	0.314	0.827	1.736	4.150	1.044*	0.631	0.468*	0.430*
14	0.366	0.530*	0.450	0.344	0.455	0.832	1.883	4.669	0.989*	0.633	0.456	0.435
15	0.363	0.447*	0.481	0.347	0.542	0.830	1.797	5.022	0.954*	0.623	0.449	0.437
16	0.362	1.048*	0.451	0.356	0.899	0.804	1.706	5.276	0.914	0.609	0.439	0.427
17	0.358	0.882*	0.436	0.366	0.774	0.774	1.630	5.101	0.878	0.602	0.438*	0.418
18	0.353	0.650*	0.434	0.361	0.682	0.761	1.539	4.845	0.857	0.596	0.436*	0.418
19	0.354	0.500*	0.651	0.365	0.675	0.738	1.427	4.254	0.856	0.584	0.437*	0.499
20	0.353	0.436*	0.891	0.363	0.720	0.727	1.370	3.769	0.822	0.573	0.449	0.499
21	0.348	0.533*	0.641	0.361	1.187	0.714	1.458	3.516	0.792	0.553	0.449	0.438
22	0.345	0.779*	0.560	0.359	1.482	0.703	1.850	3.451	0.778	0.539	0.436*	0.427
23	0.344	0.585*	0.523	0.373	1.121	0.688	2.727	3.217	0.769	0.539	0.437*	0.428
24	0.345	0.508*	0.507	0.371	0.920	0.692	3.863	2.928	0.748	0.541	0.449*	0.441
25	0.345	0.457*	0.492	0.364	0.813	0.738	4.441	2.739	0.811	0.535	0.435*	0.487
26	0.362	0.432*	0.475	0.370	0.749	0.845	4.531	2.607	0.745	0.526	0.428*	0.535
27	0.352	0.419*	0.462	0.368	0.722	0.943	4.988	2.340	0.760	0.522	0.421*	0.453
28	0.391	0.393*	0.450	0.368	0.709	0.966	5.488	2.146	0.780	0.524	0.418*	0.475
29	0.376	0.392*	0.436	0.367		0.951	5.201	1.935	0.743	0.520	0.417*	0.516
30	0.358	0.385*	0.431	0.365		0.923	5.216	1.747	0.697	0.510	0.419*	0.462
31	0.361		0.429	0.365		0.899		1.613		0.509*	0.424*	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	11.400	13.279	14.838	11.481	16.906	24.501	63.503	130.274	28.959	19.022	14.071	12.900
TOTAL FLOW (cms days)	0.323	0.376	0.420	0.325	0.479	0.694	1.798	3.689	0.820	0.539	0.398	0.365
TOTAL DEPTH (in)	0.853	0.994	1.111	0.859	1.265	1.834	4.753	9.751	2.168	1.424	1.053	0.966
TOTAL DEPTH (cm)	2.167	2.524	2.821	2.183	3.214	4.658	12.073	24.767	5.505	3.616	2.675	2.452

ANNUAL SUMMARY:
Sum of Mean Daily Flow 361.134 cfs = 10.227 cms
Total Depth 27.030 in = 68.657 cm
Maximum Instantaneous Flow 8.712 cfs = 0.247 cms on May 2 at 20.80 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 3
WATERSHED AREA: 318 ACRES (128 HECTARES)

WATER YEAR 1983
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.439	0.479	0.407	0.405	0.436	0.617	1.133	5.309	1.435	0.860	0.507	0.458
2	0.429	0.464	0.404	0.404	0.434	0.825	1.148	6.248	1.299	0.842	0.496	0.470
3	0.422	0.452	0.405	0.399	0.431	0.942	1.106	5.941	1.141	0.757	0.495	0.449
4	0.496	0.447	0.423	0.390	0.431	1.073	1.070	5.627	1.142	0.713	0.491	0.445
5	0.450	0.447	0.422	0.566	0.427	1.093	1.055	5.598	1.086	0.686	0.478	0.436
6	0.433	0.447	0.423	0.602	0.420	1.060	1.075	5.047	1.027	0.672	0.476	0.435
7	0.490	0.439	0.415	0.570	0.416	0.979	1.118	4.504	0.983	0.662	0.470	0.430
8	0.454	0.435	0.410	0.552	0.412	0.933	1.196	4.057	1.022	0.649	0.465	0.426
9	0.441	0.435	0.409	0.517	0.424	1.059	1.255	3.493	0.950	0.652	0.508	0.429
10	0.425	0.435	0.409	0.499	0.425	1.530	1.220	3.085	0.908	0.670	0.542	0.432
11	0.419	0.429	0.407	0.478	0.419	2.523	1.171	2.752	0.931	0.643	0.502	0.426
12	0.409	0.422	0.406	0.473	0.426	2.521	1.136	2.538	0.884	0.634	0.471	0.424
13	0.406	0.419	0.408	0.470	0.439	2.162	1.113	2.358	0.841	0.629	0.462	0.422*
14	0.400	0.410	0.410	0.467	0.429	2.043	1.120	2.270	0.821	0.696	0.473	0.420*
15	0.399	0.412	0.415	0.460	0.427	1.786	1.210	2.330	0.823	0.654	0.476	0.412*
16	0.404	0.419	0.428	0.453	0.430	1.610	1.423	2.222	0.802	0.602*	0.470	0.415*
17	0.407	0.425	0.445	0.449	0.435	1.471	1.741	2.204	0.782	0.603*	0.457	0.409*
18	0.405	0.449	0.425	0.447	0.529	1.350	2.144	2.302	0.773	0.597*	0.455	0.407*
19	0.409	0.431	0.426	0.445	0.495	1.244	2.977	2.298	0.770	0.602*	0.508	0.405*
20	0.409	0.426	0.430	0.440	0.485	1.165	3.877	2.373	0.746	0.603	0.545	0.411*
21	0.414	0.423	0.489	0.438	0.481	1.125	4.820	2.477	0.735	0.592	0.539	0.417*
22	0.418	0.409	0.487	0.437	0.478	1.091	5.533	2.477	0.720	0.578	0.562	0.414*
23	0.548	0.404	0.460	0.437	0.477	1.070	6.402	2.441	0.705	0.573	0.523	0.406*
24	0.455	0.403	0.444	0.438	0.531	1.031	8.821	2.382	0.695	0.567	0.486	0.408*
25	0.446	0.402	0.442	0.433	0.599	1.002	6.451	2.278	0.691	0.562	0.473	0.419*
26	0.602	0.395	0.441	0.426	0.632	0.972	5.008	2.146	0.696	0.564	0.460	0.419*
27	0.516	0.394	0.431	0.464	0.618	0.978	4.199	1.995	0.767	0.556	0.459*	0.403*
28	0.483	0.415	0.426	0.447	0.599	0.949	3.792	1.847	0.741	0.541	0.448*	0.389*
29	0.491	0.417	0.418	0.439		0.930	4.037	1.711	0.725	0.535	0.436*	0.387*
30	0.510	0.412	0.414	0.438		1.115	4.485	1.594	0.712	0.525	0.434*	0.618*
31	0.494		0.410	0.437		1.170		1.528		0.517	0.436	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	13.925	12.795	13.192	14.320	13.183	39.417	82.837	95.431	26.352	19.534	15.004	12.841
TOTAL FLOW (cms days)	0.394	0.362	0.374	0.406	0.373	1.116	2.346	2.703	0.746	0.553	0.425	0.364
TOTAL DEPTH (in)	1.042	0.958	0.987	1.072	0.987	2.950	6.200	7.143	1.972	1.462	1.123	0.961
TOTAL DEPTH (cm)	2.647	2.432	2.508	2.722	2.506	7.494	15.748	18.143	5.010	3.714	2.852	2.441

ANNUAL SUMMARY:
Sum of Mean Daily Flow 358.831 cfs = 10.162 cms
Total Depth 26.858 in = 68.219 cm
Maximum Instantaneous Flow 9.700 cfs = 0.275 cms on April 24 at 05.27 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 3
WATERSHED AREA: 318 ACRES (128 HECTARES)

WATER YEAR 1984
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.454*	0.520	0.484	0.426*	0.402	0.425	0.778	1.711	1.327	0.764	0.525	0.488
2	0.437*	0.555	0.481	0.426*	0.404	0.427	0.857	1.986	1.267	0.771	0.516	0.467
3	0.426*	0.497	0.481	0.426*	0.406	0.419	0.913	1.986	1.203	0.752	0.496	0.462
4	0.421	0.502	0.477	0.427*	0.406	0.425	1.012	1.910	1.234	0.737	0.489	0.452
5	0.417	0.486	0.468	0.429*	0.407	0.426	1.136	1.845	1.221	0.720	0.525	0.450
6	0.412	0.555	0.474	0.429*	0.410	0.439	1.231	1.741	1.210	0.721	0.508	0.486
7	0.408*	0.544	0.479	0.427*	0.412	0.466	1.163	1.790	1.202	0.702	0.502	0.468
8	0.411*	0.498	0.477	0.427*	0.414	0.499	1.296	2.037	1.232	0.689	0.495	0.473
9	0.475*	0.484	0.477	0.428*	0.414	0.580	1.226	2.754	1.198	0.680	0.492	0.460
10	0.444*	0.507	0.491	0.428*	0.412	0.633	1.166	2.910	1.165	0.669	0.485	0.451
11	0.426*	0.684	0.484	0.427*	0.408	0.608	1.078	3.098	1.135	0.660	0.480	0.434
12	0.416*	0.595	0.477	0.428*	0.409	0.584	1.040	3.715	1.095*	0.652	0.481	0.429*
13	0.423*	0.571	0.475	0.428*	0.448	0.575	1.010	4.458	1.077*	0.641	0.481	0.422*
14	0.426*	0.533	0.477	0.427*	0.437	0.612	1.121	4.980	1.079	0.628	0.476	0.418*
15	0.421*	0.526	0.468	0.427	0.419	0.609	1.911	4.742	1.009	0.619	0.464	0.415*
16	0.413*	0.532	0.458	0.425	0.421	0.608	3.840	3.930	0.984	0.607	0.475	0.414*
17	0.413*	0.570	0.454	0.422	0.415	0.615	4.840	3.269	0.937	0.601	0.468	0.411*
18	0.411*	0.550	0.454	0.423	0.412	0.603	4.623	2.920	0.912	0.600	0.457	0.405*
19	0.412*	0.529	0.456	0.429	0.412	0.596	3.776	2.829	0.878*	0.595	0.456	0.417
20	0.414	0.521	0.450	0.434	0.413	0.688	3.040	2.789	1.098*	0.588	0.461	0.474
21	0.415	0.506	0.443	0.438	0.414	0.915	2.883	2.563	1.220*	0.581	0.460	0.437
22	0.418	0.491	0.433	0.434	0.411	0.869	3.186	2.368	1.051*	0.605	0.468	0.428
23	0.493	0.490	0.431	0.430	0.408	0.805	3.386	2.342	0.971*	0.599	0.474	0.431
24	0.434	0.512	0.430	0.426	0.412	0.780	3.106	2.132	0.903*	0.579	0.465	0.434
25	0.414	0.504	0.430	0.440	0.416	0.741	2.615	1.987	0.850*	0.567	0.458	0.435
26	0.404	0.491	0.430*	0.407	0.413	0.714	2.314	1.949	0.821*	0.760	0.455	0.405*
27	0.406	0.491	0.431*	0.403	0.411	0.687	2.105	1.764	0.821*	0.620	0.459	0.400*
28	0.434	0.493	0.432*	0.400	0.413	0.668	1.934	1.646	0.833	0.606	0.453	0.400*
29	0.460	0.487	0.431*	0.400	0.416	0.648	1.773	1.552	0.790	0.571	0.444	0.406*
30	0.475	0.484	0.430*	0.400		0.656	1.686	1.473	0.766	0.546	0.528	0.402*
31	0.511		0.428*	0.401		0.700		1.395		0.530	0.558	

MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	13.342	15.707	14.189	13.122	11.996	19.022	62.044	78.570	31.490	19.961	14.953	13.075
TOTAL FLOW (cms days)	0.378	0.445	0.402	0.372	0.340	0.539	1.757	2.225	0.892	0.565	0.423	0.370
TOTAL DEPTH (in)	0.999	1.176	1.062	0.982	0.898	1.424	4.644	5.881	2.357	1.494	1.119	0.979
TOTAL DEPTH (cm)	2.537	2.986	2.697	2.495	2.281	3.616	11.795	14.937	5.987	3.795	2.843	2.486

ANNUAL SUMMARY:
Sum of Mean Daily Flow 307.471 cfs = 8.708 cms
Total Depth 23.014 in = 58.454 cm
Maximum Instantaneous Flow 5.702 cfs = 0.161 cms on May 14 at 23.14 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 3
WATERSHED AREA: 318 ACRES (128 HECTARES)

WATER YEAR 1985
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.402*	0.444	0.467	0.436	0.402	0.387	0.576	1.441	0.623	0.386*	0.363	0.340*
2	0.400*	0.538	0.466	0.434	0.403	0.388	0.762	1.539	0.587	0.388	0.372	0.359*
3	0.403*	0.524	0.463	0.433	0.400	0.387	0.956	1.503	0.559	0.385	0.366	0.342*
4	0.398*	0.475	0.461	0.428	0.397	0.386	0.983	1.403	0.546	0.381	0.352	0.333
5	0.392	0.464	0.460	0.428	0.396	0.388	1.048	1.262	0.549	0.377	0.348	0.336
6	0.391	0.471	0.456	0.425	0.397	0.389	1.213	1.162	0.545	0.374	0.345	0.375
7	0.392	0.472	0.455	0.426	0.400	0.389	1.434	1.089	0.532	0.372	0.340	0.437
8	0.393	0.466	0.454	0.432	0.401	0.389	2.088	1.033	0.510	0.369	0.340	0.404
9	0.394	0.460	0.462	0.437	0.393	0.393	2.342	0.975	0.495	0.369	0.338	0.487
10	0.392	0.463	0.474	0.436	0.389	0.407	2.493	0.929	0.483	0.365	0.342	0.392
11	0.456	0.464	0.471	0.431	0.390	0.414	2.658	0.875	0.473	0.376	0.344	0.484
12	0.405	0.487	0.471	0.428	0.394	0.424	2.486	0.819	0.468	0.377	0.344	0.439
13	0.448	0.559	0.470	0.424	0.388	0.443	2.524	0.781	0.469	0.347*	0.339	0.388
14	0.406	0.522	0.466	0.422	0.387	0.468	2.783	0.828	0.485	0.336*	0.341*	0.380
15	0.406	0.493	0.468	0.419	0.389	0.496	3.035	0.809	0.475	0.332*	0.342*	0.377
16	0.404	0.481	0.468	0.412	0.388	0.536	3.048	0.789	0.466	0.328*	0.342*	0.369
17	0.411	0.474	0.463	0.410	0.384	0.589	2.851	0.762	0.458	0.326*	0.341*	0.513
18	0.417	0.472	0.460	0.409	0.380	0.658	2.605	0.721	0.449	0.323*	0.414*	0.418
19	0.426	0.466	0.453	0.408	0.375	0.708	2.334	0.697	0.438	0.320*	0.426*	0.395
20	0.427	0.468	0.446	0.408	0.381	0.720	1.956	0.686	0.434*	0.327*	0.342*	0.387
21	0.430	0.472	0.439	0.409	0.381	0.704	1.681	0.661	0.429*	0.329*	0.341*	0.378
22	0.435	0.470	0.437	0.412	0.382	0.642	1.470	0.633	0.424*	0.326*	0.341*	0.368
23	0.440	0.468	0.436	0.414	0.384	0.612	1.327	0.609	0.419*	0.324*	0.341*	0.361
24	0.437	0.486	0.434	0.417	0.387	0.625	1.196	0.595	0.417*	0.323*	0.341*	0.357
25	0.437	0.468	0.434	0.411	0.384	0.586	1.119	0.588	0.414*	0.325*	0.340*	0.355
26	0.516	0.464	0.435	0.406	0.382	0.563	1.069	0.590	0.410*	0.334	0.340*	0.351
27	0.462	0.472	0.436	0.408	0.381	0.553	1.093	0.578	0.405*	0.336	0.339*	0.349
28	0.460	0.477	0.441	0.409	0.382	0.538	1.156	0.573	0.401*	0.340	0.341*	0.350
29	0.461	0.468	0.437	0.407		0.528	1.241	0.654	0.395*	0.356	0.341*	0.351
30	0.450	0.476	0.441	0.403		0.523	1.303	0.657	0.391*	0.407	0.340*	0.352
31	0.447		0.437	0.401		0.524		0.610		0.375	0.340*	

MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	13.138	14.383	14.059	12.984	10.899	15.754	52.828	26.850	14.148	10.937	10.824	11.526
TOTAL FLOW (cms days)	0.372	0.407	0.398	0.368	0.309	0.446	1.496	0.760	0.401	0.310	0.307	0.326
TOTAL DEPTH (in)	0.983	1.077	1.052	0.972	0.816	1.179	3.954	2.010	1.059	0.819	0.810	0.863
TOTAL DEPTH (cm)	2.498	2.734	2.673	2.468	2.072	2.995	10.043	5.105	2.690	2.079	2.058	2.191

ANNUAL SUMMARY:
Sum of Mean Daily Flow 208.331 cfs = 5.900 cms
Total Depth 15.593 in = 39.607 cm
Maximum Instantaneous Flow 3.208 cfs = 0.091 cms on April 15 at 22.79 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 4
WATERSHED AREA: 252 ACRES (101 HECTARES)

WATER YEAR 1965
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.028*	0.088*	0.204	0.336	0.384	0.476	0.672	1.815	0.713	0.314	0.162	0.148
2	0.025*	0.137*	0.212	0.342	0.381	0.468	0.901	2.149	0.667	0.309	0.167	0.148
3	0.024*	0.129*	0.189	0.359	0.372	0.461	0.925	2.517	0.635	0.297	0.167	0.147
4	0.030*	0.090*	0.173	0.339	0.367	0.461	0.940	2.723	0.619	0.295	0.160	0.148
5	0.038*	0.080*	0.166	0.347	0.366	0.474	0.976	2.529	0.591	0.289	0.156	0.148
6	0.043*	0.074*	0.162	0.389	0.361	0.509	1.062	2.176	0.567	0.283	0.154	0.151
7	0.042*	0.071*	0.159	0.346	0.354	0.566	1.123	2.003	0.546	0.277	0.149	0.154
8	0.058*	0.063*	0.156	0.317	0.354	0.628	1.187	1.883	0.520	0.285	0.145	0.161
9	0.066*	0.064*	0.155	0.311	0.346	0.671	1.305	1.916	0.503	0.273	0.144	0.154
10	0.054*	0.117	0.159	0.304	0.340	0.688	1.307	1.911	0.487	0.250	0.144	0.149
11	0.050*	0.148	0.160	0.298	0.332	0.692	1.322	2.064	0.469	0.247	0.148	0.146
12	0.049*	0.151	0.154	0.292	0.329	0.675	1.374	2.201	0.460	0.246	0.207	0.143
13	0.049*	0.152	0.152	0.287	0.326	0.677	1.542	2.409	0.485	0.239	0.176	0.146
14	0.049*	0.152	0.157	0.286	0.322	0.676	1.817	2.438	0.456	0.224	0.152	0.150
15	0.090*	0.152	0.160	0.283	0.314	0.677	2.262	2.259	0.447	0.207	0.149	0.175
16	0.107*	0.151	0.156	0.276	0.311	0.685	2.731	2.253	0.471	0.201	0.151	0.173
17	0.070*	0.150	0.154	0.272	0.316	0.682	2.632	2.170	0.453	0.199	0.148	0.161
18	0.059*	0.150	0.154	0.271	0.314	0.672	2.480	1.838	0.427	0.202	0.147	0.157
19	0.059*	0.150	0.154	0.277	0.311	0.650	2.900	1.762	0.406	0.200	0.222	0.155
20	0.063*	0.150	0.157	0.274	0.321	0.629	2.737	1.695	0.392	0.207	0.208	0.153
21	0.064*	0.150	0.391	0.272	0.334	0.606	2.142	1.621	0.381	0.198	0.220	0.151
22	0.064*	0.150	2.600	0.272	0.345	0.593	1.643	1.889	0.370	0.190	0.198	0.149
23	0.064*	0.149	2.173	0.279	0.342	0.572	1.154	1.635	0.361	0.184	0.188	0.147
24	0.064*	0.217	1.385	0.287	0.343	0.550	1.027	1.544	0.335	0.177	0.173	0.133
25	0.064*	0.324	1.059	0.279	0.344	0.541	0.975	1.436	0.321	0.175	0.169	0.120
26	0.067*	0.193	0.807	0.274	0.359	0.527	1.081	1.345	0.325	0.175	0.167	0.118
27	0.070*	0.180	0.634	0.276	0.510	0.511	1.119	1.024	0.318	0.172	0.162	0.116
28	0.068*	0.170	0.532	0.276	0.487	0.498	1.093	0.888	0.306	0.169	0.160	0.123
29	0.066*	0.162	0.460	0.377		0.492	1.223	0.834	0.297	0.167	0.157	0.120
30	0.066*	0.191	0.413	0.405		0.483	1.545	0.808	0.295	0.165	0.154	0.116
31	0.066*		0.355	0.406		0.531		0.765		0.161	0.149	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	1.778	4.304	14.098	9.606	9.885	18.019	45.195	56.499	13.620	6.975	5.151	4.358
TOTAL FLOW (cms days)	0.050	0.122	0.399	0.272	0.280	0.510	1.280	1.600	0.386	0.198	0.146	0.123
TOTAL DEPTH (in)	0.168	0.406	1.332	0.907	0.934	1.702	4.269	5.336	1.286	0.659	0.486	0.412
TOTAL DEPTH (cm)	0.427	1.032	3.382	2.305	2.372	4.323	10.842	13.554	3.267	1.673	1.236	1.046

ANNUAL SUMMARY:
Sum of Mean Daily Flow 189.487 cfs = 5.366 cms
Total Depth 17.897 in = 45.459 cm
Maximum Instantaneous Flow 6.612 cfs = 0.187 cms on December 22 at 20.50 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 4
WATERSHED AREA: 252 ACRES (101 HECTARES)

WATER YEAR 1966
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.114	0.123	0.158	0.174	0.177	0.124	1.002	0.477	0.213*	0.138*	0.100*	0.097
2	0.111	0.123	0.168	0.163	0.177	0.122	0.996	0.488	0.208*	0.140*	0.098*	0.097
3	0.110	0.123	0.177	0.159	0.178	0.121	0.845	0.496	0.203*	0.139*	0.098*	0.097
4	0.108	0.123	0.180	0.158	0.178	0.122	0.738	0.500	0.199*	0.137*	0.098*	0.096
5	0.105	0.123	0.189	0.149	0.178	0.123	0.711	0.488	0.196*	0.134*	0.098*	0.095
6	0.106	0.123	0.185	0.316	0.167	0.124	0.733	0.463	0.191*	0.129*	0.097*	0.096
7	0.105	0.123	0.182	0.257	0.162	0.126	0.802	0.425	0.184*	0.124*	0.097*	0.095
8	0.105	0.122	0.179	0.190	0.162	0.127	0.880	0.382	0.182*	0.123*	0.097*	0.092
9	0.106	0.121	0.176	0.162	0.161	0.128	0.910	0.401	0.229*	0.123*	0.098*	0.091
10	0.101	0.121	0.179	0.162	0.160	0.172	0.968	0.369	0.205*	0.123*	0.098	0.091
11	0.101	0.128	0.180	0.161	0.155	0.173	0.936	0.367*	0.197*	0.123*	0.121	0.092
12	0.115	0.127	0.178	0.158	0.150	0.171	0.879	0.357*	0.189*	0.120*	0.117	0.094
13	0.119	0.127	0.175	0.155	0.151	0.201	0.815	0.347*	0.180*	0.117*	0.110	0.095
14	0.132	0.191	0.171	0.160	0.153	0.203	0.794	0.338*	0.171	0.118*	0.110	0.122
15	0.169	0.223	0.162	0.163	0.155	0.199	0.807	0.328*	0.174	0.119*	0.110	0.142
16	0.126	0.204	0.160	0.160	0.158	0.212	0.849	0.318*	0.174	0.119*	0.109	0.119
17	0.123	0.203	0.155	0.160	0.160	0.219	0.828	0.308*	0.165	0.119*	0.107	0.109
18	0.123	0.214	0.182	0.160	0.161	0.216	0.752	0.294*	0.154	0.119*	0.105	0.107
19	0.146	0.198	0.214	0.161	0.162	0.213	0.696	0.281*	0.154	0.117*	0.088	0.118
20	0.117	0.193	0.221	0.163	0.162	0.205	0.642	0.273*	0.152	0.115*	0.089	0.110
21	0.112	0.193	0.231	0.166	0.161	0.203	0.602	0.265*	0.153	0.115*	0.093	0.105
22	0.118	0.192	0.237	0.170	0.160	0.202	0.571	0.258*	0.156	0.114*	0.092	0.101
23	0.121	0.191	0.240	0.172	0.161	0.201	0.553	0.249*	0.163	0.112*	0.089	0.100
24	0.120	0.191	0.244	0.172	0.161	0.200	0.552	0.241*	0.166	0.109*	0.087	0.099
25	0.121	0.191	0.248	0.174	0.139	0.204	0.566	0.235*	0.154	0.108*	0.088	0.105
26	0.123	0.186	0.248	0.176	0.132	0.301	0.560	0.229*	0.149	0.106*	0.100	0.111
27	0.123	0.169	0.251	0.176	0.129	0.526	0.534	0.222*	0.144	0.105*	0.102	0.112
28	0.125	0.157	0.256	0.177	0.126	0.723	0.518	0.215*	0.142	0.105*	0.099	0.107
29	0.125	0.161	0.256	0.178		0.641	0.500	0.209*	0.140	0.103*	0.102	0.106
30	0.123	0.159	0.225	0.178		0.802	0.483	0.202*	0.138	0.101*	0.101	0.105
31	0.123		0.193	0.178		0.967		0.203		0.102*	0.097	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	3.676	4.819	6.199	5.406	4.432	8.269	22.024	10.227	5.226	3.674	3.100	3.109
TOTAL FLOW (cms days)	0.104	0.136	0.176	0.153	0.126	0.234	0.624	0.290	0.148	0.104	0.088	0.088
TOTAL DEPTH (in)	0.347	0.455	0.586	0.511	0.419	0.781	2.080	0.966	0.494	0.347	0.293	0.294
TOTAL DEPTH (cm)	0.882	1.156	1.487	1.297	1.063	1.984	5.284	2.454	1.254	0.881	0.744	0.746

ANNUAL SUMMARY:
Sum of Mean Daily Flow 80.160 cfs = 2.270 cms
Total Depth 7.571 in = 19.231 cm
Maximum Instantaneous Flow 1.101 cfs = 0.031 cms on March 31 at 17.50 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 4
WATERSHED AREA: 252 ACRES (101 HECTARES)

WATER YEAR 1967
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.105	0.116	0.223	0.184*	0.261	0.218	0.363	0.559	0.578	0.152	0.112	0.099
2	0.136	0.118	0.208	0.182*	0.249	0.224	0.351	0.564	0.526	0.151	0.111	0.100
3	0.123	0.119	0.203*	0.182*	0.236	0.222	0.354	0.588	0.493	0.152	0.111	0.101
4	0.114	0.120	0.203*	0.168*	0.227	0.223	0.375	0.654	0.463	0.152	0.112	0.102
5	0.112	0.121	0.203*	0.155*	0.221	0.225	0.409	0.745	0.459	0.142	0.110	0.101
6	0.109	0.142	0.202*	0.146*	0.214	0.227	0.421	0.876	0.451	0.139	0.110	0.108
7	0.107	0.163	0.201*	0.143*	0.211	0.226	0.457	1.167	0.429	0.137	0.109	0.109
8	0.111	0.159	0.199*	0.142*	0.209	0.226	0.487	1.570	0.389*	0.135	0.108	0.109
9	0.111	0.155	0.196*	0.142*	0.207*	0.231	0.524	1.836	0.372	0.130	0.112	0.110
10	0.110	0.155	0.194*	0.141*	0.205*	0.253	0.585	1.797	0.367	0.128	0.111	0.104
11	0.111	0.156	0.187*	0.141*	0.203*	0.245	0.621	1.563	0.361	0.126	0.111	0.173
12	0.143	0.181	0.178*	0.142*	0.203*	0.230	0.647	1.425	0.343	0.118	0.112	0.130
13	0.133	0.188	0.184*	0.160	0.204*	0.229	0.664	1.252	0.332	0.117	0.111	0.107
14	0.135	0.185	0.184*	0.178	0.201	0.222	0.683	1.167	0.319	0.121	0.110	0.098
15	0.132	0.185	0.181*	0.172	0.196	0.218	0.634	1.221	0.305	0.120	0.106	0.095
16	0.132	0.277	0.179*	0.165	0.196	0.260	0.593	1.370	0.289	0.119	0.106	0.095
17	0.131	0.187	0.178*	0.158	0.197	0.334	0.570	1.551	0.286	0.152	0.105	0.095
18	0.131	0.179	0.178*	0.150	0.192	0.374	0.561	1.540	0.277	0.125	0.105	0.091
19	0.133	0.178	0.178*	0.149	0.184	0.365	0.549	1.448	0.255	0.117	0.106	0.092
20	0.130	0.204	0.178*	0.172	0.184*	0.347	0.526	1.341	0.265	0.129	0.102	0.093
21	0.134	0.207	0.177*	0.174	0.186*	0.352	0.508	1.261	0.287	0.124	0.102	0.094
22	0.141	0.189	0.176*	0.172	0.186*	0.354	0.499	1.157	0.245	0.124	0.107	0.093
23	0.153	0.183	0.176*	0.160	0.188	0.395	0.507	0.992	0.227	0.120	0.102	0.093
24	0.147	0.183	0.174*	0.160	0.189	0.418	0.513	0.832	0.214	0.119	0.102	0.091
25	0.135	0.184	0.172*	0.163	0.192	0.402	0.528	0.720	0.202	0.117	0.100	0.091
26	0.122	0.184	0.171*	0.167	0.195	0.396	0.544	0.710	0.193	0.115	0.100	0.089
27	0.118	0.184	0.171*	0.185	0.195	0.390	0.573	0.667	0.191	0.115	0.102	0.088
28	0.117	0.185	0.179*	0.252	0.202	0.396	0.579	0.634	0.184	0.112	0.101	0.087
29	0.116	0.203	0.188	0.368		0.398	0.572	0.649	0.175	0.116	0.100	0.089
30	0.115	0.204	0.191	0.317		0.383	0.563	0.612	0.163	0.113	0.100	0.209
31	0.115		0.188	0.279		0.372		0.561		0.116	0.100	

MONTHLY SUMMARY:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	3.862	5.197	5.802	5.567	5.737	9.357	15.758	33.032	9.642	3.952	3.294	3.136
TOTAL FLOW (cms days)	0.109	0.147	0.164	0.158	0.162	0.265	0.446	0.935	0.273	0.112	0.093	0.089
TOTAL DEPTH (in)	0.365	0.491	0.548	0.526	0.542	0.884	1.488	3.120	0.911	0.373	0.311	0.296
TOTAL DEPTH (cm)	0.926	1.247	1.392	1.336	1.376	2.245	3.780	7.925	2.313	0.948	0.790	0.752

ANNUAL SUMMARY:
Sum of Mean Daily Flow 104.335 cfs = 2.955 cms
Total Depth 9.855 in = 25.031 cm
Maximum Instantaneous Flow 1.969 cfs = 0.056 cms on May 9 at 21.75 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 4
WATERSHED AREA: 252 ACRES (101 HECTARES)

WATER YEAR 1968
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.156	0.125	0.117	0.123	0.111*	0.482	0.555	0.399	0.213	0.185	0.066	0.075*
2	0.178	0.125	0.117	0.123	0.112*	0.504	0.643	0.395	0.210	0.184	0.066	0.077*
3	0.271	0.122	0.117	0.120	0.113*	0.513	0.633*	0.388	0.213	0.176	0.066	0.076*
4	0.199	0.119	0.119	0.117	0.114*	0.532	0.617*	0.377	0.207	0.162	0.067	0.069*
5	0.163	0.119	0.127	0.116	0.112*	0.571	0.716	0.381	0.206	0.162	0.067	0.064*
6	0.129	0.119	0.123	0.169	0.110*	0.576	0.679	0.371	0.226	0.157	0.067	0.137
7	0.121	0.118	0.123	0.136	0.108*	0.529	0.662	0.362	0.209	0.151	0.067	0.131
8	0.117	0.117	0.121	0.135	0.105*	0.479	0.637	0.338	0.191	0.149	0.069	0.118
9	0.116	0.122	0.118	0.130	0.105*	0.438	0.621	0.320	0.204	0.148	0.089	0.106
10	0.117	0.150	0.116	0.124	0.105*	0.402	0.638	0.310	0.194	0.143	0.109	0.097
11	0.119	0.152	0.115	0.119	0.104*	0.349	0.689	0.309	0.192	0.134	0.081	0.090
12	0.127	0.142	0.123*	0.116	0.102*	0.327	0.681	0.350	0.193	0.128	0.077	0.089
13	0.124	0.132	0.119*	0.115	0.101*	0.333	0.652	0.359	0.184	0.129	0.120	0.089
14	0.123	0.126	0.119*	0.110*	0.101*	0.321	0.626*	0.336	0.177	0.124	0.248	0.091
15	0.121	0.124	0.118*	0.115*	0.101*	0.309	0.600*	0.325	0.170	0.119	0.222*	0.101
16	0.119	0.123	0.117*	0.123*	0.100*	0.304	0.575	0.310	0.164	0.119	0.122*	0.097
17	0.118	0.122	0.117	0.123*	0.097*	0.299	0.551	0.290	0.163	0.120	0.076*	0.097
18	0.119	0.127	0.116*	0.121*	0.098	0.290	0.522	0.284	0.177	0.120	0.085*	0.097
19	0.121	0.124	0.115*	0.115*	0.334	0.278	0.491	0.271	0.195	0.120	0.089*	0.097
20	0.121	0.122	0.115*	0.115*	0.919	0.273	0.457	0.297	0.202	0.119	0.101*	0.111
21	0.133	0.120	0.114*	0.121*	0.637	0.276	0.440	0.258	0.197	0.113	0.111*	0.121
22	0.134	0.118	0.113*	0.121*	0.508	0.293	0.401	0.247	0.202	0.108	0.129*	0.110
23	0.132	0.117	0.112*	0.120*	0.571	0.323	0.374	0.241	0.208	0.104	0.149*	0.105
24	0.127	0.125	0.118	0.118*	0.566	0.352*	0.363	0.232	0.195	0.098	0.133*	0.102
25	0.128	0.122	0.137	0.117*	0.514	0.382*	0.360	0.318	0.192	0.093	0.112*	0.100
26	0.123	0.121	0.155	0.117*	0.476	0.385	0.364	0.279	0.191	0.089	0.097*	0.099
27	0.169	0.120	0.142	0.116*	0.450	0.386*	0.361	0.262	0.190	0.084	0.091*	0.104
28	0.243	0.119	0.133	0.115*	0.445	0.410	0.364	0.245	0.189	0.076	0.089*	0.108
29	0.137	0.119	0.125	0.116*	0.459	0.455	0.386	0.226	0.189	0.071	0.084*	0.107
30	0.130	0.118	0.123	0.115*		0.500	0.406	0.219	0.188	0.069	0.079*	0.106
31	0.127		0.123	0.111*		0.506		0.214		0.067	0.076*	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	4.361	3.728	3.769	3.754	7.775	12.380	16.064	9.513	5.827	3.821	3.104	2.972
TOTAL FLOW (cms days)	0.124	0.106	0.107	0.106	0.220	0.351	0.455	0.269	0.165	0.108	0.088	0.084
TOTAL DEPTH (in)	0.412	0.352	0.356	0.355	0.734	1.169	1.517	0.899	0.550	0.361	0.293	0.281
TOTAL DEPTH (cm)	1.046	0.894	0.904	0.901	1.865	2.970	3.854	2.282	1.398	0.917	0.745	0.713

ANNUAL SUMMARY:
Sum of Mean Daily Flow 77.067 cfs = 2.183 cms
Total Depth 7.279 in = 18.489 cm
Maximum Instantaneous Flow 1.249 cfs = 0.035 cms on February 20 at 02.40 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 4
WATERSHED AREA: 252 ACRES (101 HECTARES)

WATER YEAR 1969
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.106	0.123	0.151	0.113	0.203*	0.200	1.339	1.419	0.339	0.192	0.084	0.067
2	0.106	0.121	0.146	0.116	0.194	0.199	1.463	1.340	0.314	0.192	0.083	0.067
3	0.105	0.125	0.144	0.119	0.191	0.199	1.549	1.262	0.318	0.196	0.082	0.066
4	0.105	0.126	0.145	0.117	0.188	0.199	1.508	1.275	0.319	0.178	0.080	0.064
5	0.105	0.123	0.147	0.152	0.189	0.202	1.810	1.312	0.350*	0.176	0.080	0.064
6	0.105	0.122	0.148	0.182	0.188	0.206	2.236	1.414	0.378*	0.179	0.080	0.064
7	0.105	0.121	0.144	0.169	0.186	0.206	1.911	1.465*	0.354*	0.179	0.080	0.064
8	0.105	0.121	0.144	0.156	0.184	0.206	1.627	1.462	0.344*	0.170	0.080	0.062
9	0.105	0.179	0.144	0.155	0.183	0.206	1.684	1.394	0.349*	0.164	0.080	0.056
10	0.105	0.137	0.156	0.153	0.186	0.206	1.878	1.319	0.341*	0.153	0.080	0.056
11	0.117	0.157	0.200	0.150	0.191	0.206	1.949	1.239	0.317*	0.146	0.080	0.056
12	0.138	0.236	0.170	0.151	0.198	0.206	2.075	1.144	0.299*	0.141	0.080	0.056
13	0.140	0.172	0.159*	0.174	0.199	0.207	2.259	1.056	0.293*	0.136	0.081	0.056
14	0.124	0.152	0.152	0.178	0.196	0.209	2.193	1.083	0.283*	0.133	0.082	0.057
15	0.128	0.143	0.150	0.183	0.195	0.217	2.058	0.956	0.273*	0.129	0.082	0.058
16	0.131	0.139	0.159	0.182	0.195	0.231	2.012	0.841	0.264*	0.125	0.080	0.058
17	0.130	0.135	0.153	0.182	0.195	0.263	2.067	0.764	0.253*	0.123	0.079	0.058
18	0.129	0.149	0.150	0.182	0.193	0.277	2.420	0.733	0.243*	0.119	0.076	0.057
19	0.128	0.154	0.149	0.183	0.194	0.279	2.203	0.715	0.233*	0.115	0.074	0.072
20	0.130	0.148	0.141	0.195	0.195	0.279	1.992	0.713	0.202	0.109	0.074	0.109
21	0.134	0.146	0.167	0.470	0.196	0.285	2.070	0.635	0.194	0.096	0.074	0.096
22	0.129	0.185	0.167	0.379	0.197	0.326	2.657	0.588	0.185	0.096	0.074	0.092
23	0.129	0.171	0.157	0.333	0.198	0.352	3.129	0.573	0.208	0.096	0.074	0.089
24	0.127	0.164	0.140*	0.304	0.200	0.356	2.951	0.543	0.335	0.095	0.074	0.087
25	0.125	0.159	0.127	0.283	0.201	0.379	2.350	0.511	0.257	0.095	0.074	0.087
26	0.124	0.155	0.125	0.284	0.201	0.454	1.972	0.465	0.230	0.096	0.072	0.087
27	0.123	0.154	0.123	0.263	0.201	0.544	1.774	0.444	0.227	0.095	0.069	0.087
28	0.123	0.152	0.124	0.250	0.201	0.591	1.683	0.423	0.221	0.094	0.069	0.087
29	0.122	0.152	0.123	0.239		0.732	1.639	0.407	0.213	0.087	0.069	0.091
30	0.122	0.152	0.122	0.227		0.948	1.515	0.411	0.202	0.084	0.069	0.096
31	0.123		0.119	0.220*		1.248		0.367		0.084	0.068	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	3.725	4.471	4.545	6.445	5.440	10.618	59.973	28.272	8.335	4.071	2.382	2.166
TOTAL FLOW (cms days)	0.105	0.127	0.129	0.183	0.154	0.301	1.698	0.801	0.236	0.115	0.067	0.061
TOTAL DEPTH (in)	0.352	0.422	0.429	0.609	0.514	1.003	5.665	2.670	0.787	0.384	0.225	0.205
TOTAL DEPTH (cm)	0.894	1.073	1.090	1.546	1.305	2.547	14.388	6.783	2.000	0.977	0.571	0.520

ANNUAL SUMMARY:
Sum of Mean Daily Flow 140.443 cfs = 3.977 cms
Total Depth 13.265 in = 33.693 cm
Maximum Instantaneous Flow 3.877 cfs = 0.110 cms on April 23 at 20.25 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 4
WATERSHED AREA: 252 ACRES (101 HECTARES)

WATER YEAR 1970
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.096	0.115	0.063*	0.093*	0.128*	0.223*	0.206*	0.754*	0.779	0.344	0.105	0.063
2	0.104	0.115	0.062*	0.092*	0.124*	0.206*	0.197*	0.730*	0.738	0.317	0.104	0.062
3	0.078	0.115	0.061*	0.092*	0.118*	0.186*	0.186*	1.050*	0.700	0.294	0.103	0.061
4	0.070	0.115	0.062*	0.092*	0.110*	0.167*	0.185*	1.531*	0.667	0.279	0.103	0.078
5	0.066	0.115	0.063*	0.092*	0.101*	0.148*	0.243*	2.118*	0.638	0.260	0.101	0.080
6	0.065	0.124	0.062*	0.092*	0.100*	0.133*	0.427*	2.591*	0.608	0.244	0.097	0.077
7	0.064	0.130	0.061*	0.093*	0.105*	0.129*	0.855*	2.671	0.586	0.234	0.094	0.075
8	0.082	0.123	0.061*	0.095*	0.110*	0.145*	1.096*	2.400*	0.566	0.216	0.090	0.153
9	0.141	0.121	0.061*	0.096*	0.119*	0.153*	1.020*	2.379*	0.549	0.208	0.085	0.095
10	0.138	0.121	0.061*	0.097*	0.132*	0.147*	1.196*	2.332*	0.535	0.233	0.085	0.096
11	0.138	0.120	0.061*	0.097*	0.146*	0.151*	1.353*	2.092*	0.518	0.218	0.085	0.097
12	0.138	0.118	0.063*	0.097*	0.178*	0.152*	1.203*	1.828*	0.503	0.205	0.081	0.097
13	0.138	0.117	0.070*	0.101*	0.208*	0.146*	1.022*	1.608*	0.490	0.198	0.077	0.097
14	0.138	0.117	0.074*	0.108*	0.196*	0.157*	0.909*	1.454*	0.484	0.184	0.077	0.098
15	0.138	0.117	0.075*	0.115*	0.165*	0.194*	0.806*	1.415*	0.480	0.181	0.076	0.099
16	0.138	0.117	0.074*	0.116*	0.147*	0.218*	0.728*	1.567*	0.470	0.179	0.075	0.099
17	0.138	0.117	0.074*	0.122	0.162*	0.212*	0.712*	1.933*	0.460	0.179	0.074	0.099
18	0.138	0.117	0.075*	0.144	0.164*	0.194*	0.729	2.355*	0.450	0.163	0.072	0.104
19	0.138	0.117	0.078*	0.179	0.139*	0.178*	0.730	2.485*	0.440	0.158	0.071	0.150
20	0.138	0.117	0.084*	0.185	0.131*	0.171*	0.706	2.278*	0.428	0.152	0.070	0.149
21	0.138	0.117	0.139*	0.213	0.134*	0.175*	0.703	2.030*	0.416	0.152	0.071	0.135
22	0.138	0.117	0.150*	0.221	0.143*	0.187*	0.685	1.847*	0.402	0.141	0.067	0.129
23	0.132	0.095*	0.101*	0.363	0.153*	0.198*	0.675	1.787*	0.386	0.137	0.074	0.131
24	0.115	0.074*	0.093*	0.659	0.165*	0.209*	0.669	1.703*	0.373	0.133	0.069	0.125
25	0.115	0.073*	0.091*	0.344	0.176*	0.217*	0.663	1.541*	0.337*	0.134	0.064	0.123
26	0.115	0.071*	0.091*	C.247*	0.186*	0.225*	0.799*	1.412*	0.260*	0.128	0.063	0.120
27	0.115	0.070*	0.091*	0.207*	0.198*	0.239*	0.925*	1.302*	0.372	0.122	0.063	0.117
28	0.123	0.067*	0.089*	0.182*	0.218*	0.255*	0.904*	1.097	0.377	0.122	0.063	0.116
29	0.117	0.065*	0.086*	0.157*		0.249*	0.890*	0.914	0.471	0.120	0.063	0.115
30	0.115	0.064*	0.088*	0.143*		0.225*	0.891*	0.873	0.389	0.116	0.063	0.115
31	0.115		0.092*	0.133*		0.211*		0.825		0.106	0.063	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	3.626	3.185	2.457	5.067	4.155	5.798	22.314	52.902	14.872	5.854	2.444	3.158
TOTAL FLOW (cms days)	0.103	0.090	0.070	0.143	0.118	0.164	0.632	1.498	0.421	0.166	0.069	0.089
TOTAL DEPTH (in)	0.342	0.301	0.232	0.479	0.392	0.548	2.108	4.997	1.405	0.553	0.231	0.298
TOTAL DEPTH (cm)	0.870	0.764	0.590	1.216	0.997	1.391	5.353	12.692	3.568	1.404	0.586	0.758

ANNUAL SUMMARY:
Sum of Mean Daily Flow 125.833 cfs = 3.564 cms
Total Depth 11.885 in = 30.188 cm
Maximum Instantaneous Flow 2.845 cfs = 0.081 cms on May 7 at 00.50 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 4
WATERSHED AREA: 252 ACRES (101 HECTARES)

WATER YEAR 1971
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.112	0.130	0.248	0.248	0.407	0.480	0.709	3.854*	0.792	0.339	0.125	0.097
2	0.107	0.132	0.244	0.248	0.492	0.477	0.730	4.869	0.770	0.325	0.126	0.097
3	0.107	0.125	0.233	0.248	0.496	0.475	0.777	5.261*	0.733	0.315	0.127	0.097
4	0.108	0.130	0.236	0.248	0.500	0.457	0.828	4.826	0.693	0.302	0.126	0.096
5	0.109	0.180	0.229	0.250	0.504	0.440	0.978	5.130	0.655	0.295	0.124	0.095
6	0.110	0.196	0.259	0.254	0.504	0.432	1.251	4.505	0.611	0.291	0.123	0.096
7	0.110	0.193	0.285	0.266	0.505	0.431	1.918	4.283	0.583	0.287	0.122	0.109
8	0.110	0.173	0.287	0.269	0.498	0.430	1.999	3.966	0.559*	0.281	0.120	0.100
9	0.124	0.254	0.271	0.271	0.482	0.433	1.959	3.814	0.522*	0.278	0.118	0.097
10	0.143	0.224	0.255	0.272	0.491	0.416	2.035	3.507	0.492*	0.276	0.108	0.096
11	0.134	0.195	0.254	0.274	0.473	0.412	1.966	3.300	0.461*	0.275	0.106	0.096
12	0.132	0.195	0.243	0.275	0.465	0.425	1.796	3.101	0.429	0.275	0.106	0.096
13	0.131	0.175	0.237	0.275	0.481	0.423	1.764	2.948	0.417	0.259	0.106	0.096
14	0.130	0.166	0.234	0.275	0.505	0.401	1.966	2.445	0.408	0.233	0.106	0.095
15	0.129	0.164	0.234	0.275	0.547	0.390	2.425	2.116	0.396	0.221	0.106	0.094
16	0.129	0.167	0.234	0.275	0.575	0.386	2.581	1.946	0.394	0.213	0.106	0.093
17	0.129	0.165	0.226	0.275	0.587	0.384	2.694	1.774	0.387	0.198	0.106	0.092
18	0.129	0.165	0.220	0.265	0.576	0.381	2.626	1.544	0.401	0.190	0.106	0.091
19	0.129	0.169	0.214	0.274	0.566	0.381	2.778	1.460	0.389	0.185	0.106	0.090
20	0.140	0.167	0.210	0.367	0.555	0.381	3.160	1.349	0.367	0.182	0.106	0.090
21	0.139	0.161	0.206	0.381	0.541	0.381	3.493	1.247	0.354	0.174	0.105	0.090
22	0.148	0.154	0.199	0.377	0.532	0.387	3.516	1.166	0.351	0.160	0.105	0.090
23	0.144	0.206	0.222	0.375	0.525	0.416	3.300	1.086	0.341	0.158	0.104	0.090
24	0.146	0.693	0.222	0.365	0.521	0.471	3.054	1.039	0.334	0.157	0.101	0.090
25	0.139	0.575	0.227	0.359	0.510	0.474	2.894	0.991	0.419	0.153	0.101	0.092
26	0.139	0.381	0.234	0.356	0.504	0.579	2.850	0.933	0.558	0.149	0.101	0.094
27	0.138	0.324	0.244	0.353	0.499	0.628	2.817	0.919	0.467	0.147	0.100	0.093
28	0.135	0.295	0.246	0.341	0.488	0.614	2.961	0.913	0.452	0.145	0.099	0.092
29	0.134	0.266	0.248	0.339		0.621	3.190	0.873	0.396	0.140	0.100	0.097
30	0.124	0.267	0.248	0.336		0.683	3.389	0.849	0.359	0.131	0.099	0.106
31	0.127		0.248	0.343		0.717		0.808		0.128	0.098	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	3.966	6.787	7.396	9.327	14.328	14.405	68.405	76.824	14.491	6.861	3.395	2.847
TOTAL FLOW (cms days)	0.112	0.192	0.209	0.264	0.406	0.408	1.937	2.176	0.410	0.194	0.096	0.081
TOTAL DEPTH (in)	0.375	0.641	0.699	0.881	1.353	1.361	6.461	7.256	1.369	0.648	0.321	0.269
TOTAL DEPTH (cm)	0.952	1.628	1.774	2.238	3.437	3.456	16.411	18.430	3.477	1.646	0.815	0.683

ANNUAL SUMMARY:

Sum of Mean Daily Flow 229.033 cfs = 6.486 cms
Total Depth 21.632 in = 54.946 cm
Maximum Instantaneous Flow 5.756 cfs = 0.163 cms on May 4 at 24.00 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 4
WATERSHED AREA: 252 ACRES (101 HECTARES)

WATER YEAR 1972
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.105	0.138	0.134	0.132	0.166	0.454	0.841	1.862	0.565*	0.273	0.134	0.103
2	0.105	0.140	0.134	0.134	0.164	0.413	0.954	1.849	0.521	0.263	0.133	0.101
3	0.103	0.140	0.134	0.136	0.163	0.509	1.051	2.010	0.510	0.252	0.131	0.099
4	0.103	0.140	0.133	0.136	0.162	0.390	1.127	2.372	0.491	0.243	0.128	0.099
5	0.103	0.141	0.133	0.136	0.162	0.358	1.380	2.642	0.463	0.235	0.126	0.172
6	0.104	0.142	0.134	0.133	0.162	0.357	1.785	2.711	0.461	0.222	0.123	0.148
7	0.104	0.142	0.133	0.130	0.159	0.355	1.866	2.716	0.463	0.221	0.120	0.131
8	0.101	0.142	0.130	0.130	0.156	0.359	1.754	2.779	0.444	0.211	0.119	0.125
9	0.097	0.143	0.128	0.130	0.156	0.453	1.697	2.479	0.436	0.213	0.120	0.128
10	0.097	0.144	0.125	0.130	0.156	0.821	1.625	2.201	0.454	0.203	0.118	0.127
11	0.099	0.146	0.123	0.129	0.156	1.163	1.570	2.037	0.436	0.194	0.115	0.129
12	0.101	0.151	0.121	0.129	0.156	1.096	1.548	1.970	0.427	0.189	0.112	0.130
13	0.103	0.151	0.117	0.129	0.163	1.191	1.437	1.989	0.423	0.183	0.115	0.127
14	0.105	0.150	0.113	0.129	0.163	1.189	1.351	2.046	0.422	0.176	0.138	0.122
15	0.105	0.149	0.113	0.129	0.162	1.199	1.282	2.050	0.415	0.176	0.147	0.123
16	0.107	0.148	0.115	0.131	0.162	1.386	1.270	1.933	0.432	0.170	0.132	0.129
17	0.110	0.147	0.115	0.135	0.167	1.766	1.215	1.776	0.415	0.166	0.121	0.129
18	0.112	0.146	0.115	0.145	0.170	2.068	1.160	1.593	0.402	0.164	0.119	0.128
19	0.113	0.146	0.114	0.183	0.170	1.823	1.128	1.427	0.394	0.181	0.115	0.152
20	0.125	0.146	0.112	0.176	0.184	1.498	1.146	1.307	0.393	0.180	0.116	0.146
21	0.122	0.146	0.119	0.272	0.196	1.407	1.245	1.191	0.393	0.179	0.115	0.136
22	0.122	0.146	0.162	0.223	0.190	1.628	1.278	1.093	0.384	0.172	0.112	0.133
23	0.123	0.146	0.182	0.199	0.189	1.887	1.375	1.017	0.379	0.161	0.114	0.132
24	0.124	0.146	0.151	0.188	0.188	1.598	1.550	0.948	0.358	0.151	0.114	0.141
25	0.125	0.146	0.150	0.183	0.184	1.398	1.598	0.883	0.409	0.145	0.112	0.143
26	0.127	0.147	0.147	0.179	0.183	1.237	1.575	0.818	0.352	0.140	0.107	0.138
27	0.129	0.146	0.143	0.175	0.331	1.103	1.704	0.764	0.328	0.139	0.105	0.148
28	0.130	0.143	0.142	0.172	0.629	0.993	2.075	0.721	0.306	0.138	0.145	0.135
29	0.132	0.141	0.138	0.170	0.718	0.902	2.337	0.673	0.295	0.138	0.120	0.132
30	0.134	0.138	0.133	0.169		0.839	2.014	0.619	0.282	0.140	0.109	0.130
31	0.136		0.132	0.168		0.823		0.592*		0.137	0.106	

MONTHLY SUMMARY:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	3.504	4.334	4.076	4.842	6.062	32.664	43.939	51.069	12.452	5.754	3.742	3.914
TOTAL FLOW (cms days)	0.099	0.123	0.115	0.137	0.172	0.925	1.244	1.446	0.353	0.163	0.106	0.111
TOTAL DEPTH (in)	0.331	0.409	0.385	0.457	0.573	3.085	4.150	4.823	1.176	0.543	0.353	0.370
TOTAL DEPTH (cm)	0.841	1.040	0.978	1.162	1.454	7.836	10.541	12.252	2.987	1.380	0.898	0.939

ANNUAL SUMMARY:
Sum of Mean Daily Flow 176.352 cfs = 4.994 cms
Total Depth 16.657 in = 42.308 cm
Maximum Instantaneous Flow 2.849 cfs = 0.081 cms on May 8 at 11.00 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 4
WATERSHED AREA: 252 ACRES (101 HECTARES)

WATER YEAR 1973
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.129	0.143	0.182	0.195	0.227	0.347	0.367	0.634	0.250	0.132	0.094	0.096
2	0.125	0.150	0.182	0.195	0.223	0.357	0.357	0.605	0.240	0.128	0.094	0.092
3	0.117	0.150	0.182	0.193	0.222	0.345	0.364	0.598	0.232	0.126	0.098	0.089
4	0.119	0.200	0.185	0.199*	0.221	0.333	0.398	0.629	0.224	0.123	0.096	0.088
5	0.115	0.190	0.220*	0.208*	0.220	0.325	0.453	0.592	0.214	0.122	0.093	0.085
6	0.119	0.172	0.189*	0.208*	0.219	0.312	0.474	0.564	0.205	0.123	0.092	0.085
7	0.117	0.168	0.194*	0.206	0.219	0.305	0.452	0.543	0.197	0.121	0.091	0.158
8	0.114	0.172	0.193*	0.203	0.219	0.301	0.447	0.566	0.192	0.120	0.090	0.111
9	0.128	0.172	0.185*	0.205	0.219	0.304	0.448	0.520	0.190	0.118	0.091	0.096
10	0.165	0.172	0.183*	0.206	0.219	0.310	0.467	0.494	0.186	0.114	0.092	0.094
11	0.185	0.173	0.186*	0.206	0.220	0.299	0.511	0.459	0.180	0.112	0.091	0.091
12	0.142	0.172	0.186*	0.220	0.216	0.292	0.598	0.429	0.178	0.111	0.089	0.091
13	0.134	0.170	0.180*	0.364	0.213	0.289	0.740	0.397	0.175	0.111	0.083	0.091
14	0.132	0.167	0.173*	0.314	0.212	0.289	0.737	0.377	0.223	0.111	0.083	0.095
15	0.140	0.164	0.167*	0.281	0.212	0.290	0.688	0.369	0.195	0.112	0.081	0.097
16	0.132	0.164	0.164*	0.456	0.212	0.296	0.682	0.361	0.188	0.111	0.081	0.095
17	0.127	0.177	0.168*	0.399	0.213	0.334	0.692	0.346	0.210	0.110	0.083	0.093
18	0.126	0.177	0.194	0.342	0.214	0.318	0.647	0.336	0.193	0.111	0.082	0.093
19	0.125	0.176	0.272	0.313	0.214	0.319	0.621	0.330	0.181	0.114	0.081	0.121
20	0.124	0.171	0.207	0.298	0.213	0.328	0.592	0.321	0.178	0.114	0.080	0.194
21	0.123	0.167	0.359	0.295	0.206	0.339	0.578	0.307*	0.174	0.114	0.086	0.121
22	0.123*	0.168	0.486	0.293	0.209	0.342	0.588	0.298*	0.163	0.107	0.086	0.111
23	0.124	0.170	0.292	0.290	0.213	0.347	0.621	0.280*	0.163	0.108	0.085	0.119
24	0.127	0.170	0.260	0.285	0.214	0.365	0.645	0.280*	0.162	0.107	0.086	0.189
25	0.129	0.171	0.229	0.270	0.219	0.403	0.666	0.313	0.154	0.103	0.092	0.152
26	0.130	0.204	0.219	0.252	0.225	0.442	0.705	0.268	0.147	0.100	0.089	0.121
27	0.131	0.186	0.214	0.248	0.260	0.438	0.753	0.258	0.143	0.099	0.088	0.115
28	0.132	0.178	0.213	0.246	0.289	0.420	0.754	0.256	0.139	0.098	0.085	0.112
29	0.132	0.176	0.211	0.244		0.404	0.718	0.256	0.142	0.096	0.084	0.110
30	0.133	0.179	0.209	0.240		0.393	0.675	0.251	0.137	0.095	0.084	0.108
31	0.138		0.201	0.234		0.383		0.253		0.094	0.098	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	4.038	5.170	6.687	8.106	6.182	10.570	17.440	12.492	5.553	3.462	2.728	3.313
TOTAL FLOW (cms days)	0.114	0.146	0.189	0.230	0.175	0.299	0.494	0.354	0.157	0.098	0.077	0.094
TOTAL DEPTH (in)	0.381	0.488	0.632	0.766	0.584	0.998	1.647	1.180	0.525	0.327	0.258	0.313
TOTAL DEPTH (cm)	0.969	1.240	1.604	1.945	1.483	2.536	4.184	2.997	1.332	0.831	0.655	0.795

ANNUAL SUMMARY:
Sum of Mean Daily Flow 85.740 cfs = 2.428 cms
Total Depth 8.098 in = 20.569 cm
Maximum Instantaneous Flow 0.925 cfs = 0.026 cms on December 22 at 06.25 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 4
WATERSHED AREA: 252 ACRES (101 HECTARES)

WATER YEAR 1974
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.108	0.197	0.256	0.223	0.423	0.462	1.964	3.336*	0.780	0.248	0.140	0.146
2	0.106	0.188	0.249	0.223*	0.412	0.413	1.797	3.377*	0.748	0.248	0.141	0.145
3	0.108	0.185	0.243	0.226*	0.404	0.398	1.682	3.295*	0.714	0.244	0.138	0.143
4	0.109	0.166	0.238	0.229*	0.396	0.389	1.530	3.340	0.711	0.239	0.136	0.142
5	0.107	0.160	0.234	0.231*	0.379	0.397	1.460	3.551	0.705	0.235	0.144	0.132
6	0.108	0.260	0.233	0.233*	0.374	0.416	1.563	3.652	0.652	0.235	0.177	0.123
7	0.164	0.207	0.274	0.235*	0.369	0.390	1.512	3.563	0.608	0.232	0.188	0.123
8	0.126	0.205	0.280	0.236*	0.358	0.371	1.518	3.588	0.568	0.246	0.172	0.123
9	0.122	0.246	0.264	0.237*	0.350	0.360	1.608	3.292	0.534	0.283	0.164	0.123
10	0.120	0.426	0.264	0.240*	0.350	0.360	1.636	2.805	0.496	0.295	0.162	0.123
11	0.119	0.498	0.262	0.242*	0.350	0.362	1.673	2.389	0.483	0.279	0.160	0.123
12	0.119	0.758	0.254	0.242*	0.350	0.434	1.788	2.168	0.464	0.237	0.158	0.122
13	0.119	0.505	0.253	0.242	0.350	0.460	1.770	1.933	0.449	0.224	0.155	0.121
14	0.119	0.371	0.251	0.292	0.347	0.460	1.830	1.758	0.424	0.216	0.158	0.120
15	0.119	0.311	0.249	0.593	0.340	0.467	2.022	1.605	0.401	0.216	0.155	0.119
16	0.117	0.339	0.277	1.153	0.338	0.536	2.282	1.471	0.393	0.206	0.151	0.119
17	0.114	0.350	0.305	1.401	0.339	1.069	2.691*	1.378	0.382	0.200	0.147	0.118
18	0.114	0.325	0.289	1.004	0.341	1.117	3.208*	1.296	0.369	0.200	0.142	0.117
19	0.114	0.296	0.283	0.900	0.342	1.099	4.120	1.225	0.357	0.197	0.160	0.114
20	0.117	0.273	0.280	0.781	0.338	1.033	3.904	1.176	0.370	0.190	0.191	0.116
21	0.119	0.262	0.280	0.695	0.333	0.997	3.746*	1.121	0.347	0.185	0.168	0.119
22	0.119	0.249	0.281	0.652	0.333	0.973	3.751*	1.082	0.329	0.180	0.160	0.120
23	0.148	0.241	0.280	0.624	0.333	0.932*	4.155*	1.095	0.316	0.179	0.159	0.122
24	0.153	0.231	0.271	0.581	0.333	0.885	5.263	1.087	0.309	0.173	0.156	0.126
25	0.174	0.230	0.266	0.549	0.333	0.934	4.969	1.101	0.298	0.165	0.153	0.129
26	0.143	0.227	0.255	0.522	0.331	1.127	4.343	1.113	0.287	0.158	0.151	0.126
27	0.138	0.221	0.251	0.497	0.330	1.343	3.728*	1.098	0.279	0.155	0.150	0.128
28	0.136	0.220	0.244	0.480	0.359	1.791	3.081	1.023	0.270	0.152	0.149	0.124
29	0.137	0.231	0.239	0.463		1.655	2.841	0.972	0.260	0.149	0.148	0.121
30	0.138	0.240	0.226	0.450		1.974	3.044*	0.903	0.253	0.146	0.147	0.117
31	0.209		0.224	0.437		2.045		0.839		0.142	0.146	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	3.966	8.617	8.055	15.115	9.933	25.650	80.477	61.633	13.557	6.454	4.825	3.742
TOTAL FLOW (cms days)	0.112	0.244	0.228	0.428	0.281	0.726	2.279	1.745	0.384	0.183	0.137	0.106
TOTAL DEPTH (in)	0.375	0.814	0.761	1.428	0.938	2.423	7.601	5.821	1.281	0.610	0.456	0.353
TOTAL DEPTH (cm)	0.951	2.067	1.932	3.626	2.383	6.154	19.307	14.786	3.252	1.548	1.157	0.898

ANNUAL SUMMARY:
Sum of Mean Daily Flow 242.023 cfs = 6.854 cms
Total Depth 22.859 in = 58.063 cm
Maximum Instantaneous Flow 5.545 cfs = 0.157 cms on April 24 at 21.00 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 4
WATERSHED AREA: 252 ACRES (101 HECTARES)

WATER YEAR 1975
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.111	0.145	0.147	0.170	0.176	0.189	0.238	0.448	0.905	0.239	0.149	0.129
2	0.110	0.148	0.146	0.175	0.174	0.212	0.236	0.580	0.890	0.231	0.146	0.125
3	0.114	0.147	0.147	0.181	0.172	0.204	0.234	0.876	0.793*	0.230	0.145	0.128
4	0.116	0.147	0.176	0.181	0.171	0.202	0.233	0.851	0.716*	0.220	0.142	0.121
5	0.124	0.147	0.167	0.180	0.168	0.201	0.231	0.737	0.677*	0.211	0.137	0.114
6	0.126	0.148	0.159	0.180	0.166	0.202	0.230	0.661	0.591	0.202	0.127	0.114
7	0.126	0.186	0.156	0.180	0.167	0.209	0.229	0.647	0.528	0.203	0.124	0.110
8	0.123	0.182	0.153	0.180	0.167	0.259	0.227	0.725	0.482	0.198	0.123	0.108
9	0.145	0.163	0.148	0.181	0.167	0.292	0.224	0.901	0.445	0.190	0.122	0.107
10	0.147	0.161	0.146	0.182	0.167	0.293	0.221	1.338	0.423	0.187	0.123	0.107
11	0.137	0.160	0.145	0.183	0.161	0.285	0.226	1.854	0.411	0.183	0.120	0.107
12	0.133	0.159	0.145	0.185	0.166	0.280	0.247	1.975	0.392	0.183	0.120	0.106
13	0.132	0.158	0.146	0.186	0.187	0.275	0.278	2.366	0.369	0.187	0.119	0.121
14	0.129	0.158	0.145	0.187	0.186	0.270	0.323	3.093	0.342	0.177	0.127	0.256
15	0.130	0.156	0.146	0.189	0.180	0.270	0.342	3.661	0.338	0.172	0.125	0.152
16	0.133	0.155	0.149	0.190	0.179	0.268	0.349	3.462	0.326	0.169	0.122	0.133
17	0.132	0.155	0.153	0.191	0.177	0.268	0.367	3.105	0.428	0.175	0.130	0.128
18	0.129	0.180	0.153	0.188	0.175	0.333	0.432	2.819	0.497	0.169	0.176	0.121
19	0.125	0.164	0.153	0.181	0.177	0.365	0.471	2.426	0.413	0.164	0.176	0.117
20	0.129	0.162	0.154	0.177	0.171	0.330	0.487	1.960	0.382	0.161	0.161	0.118
21	0.166	0.166	0.165	0.175	0.166	0.318	0.518	1.752	0.349	0.157	0.153	0.117
22	0.159	0.171	0.157	0.172	0.164	0.309	0.624	1.582	0.348	0.165	0.174	0.118
23	0.158	0.162	0.152	0.171	0.162	0.299	0.675	1.498	0.335	0.160	0.227	0.116
24	0.156	0.162	0.150	0.174	0.162	0.291	0.611	1.374	0.335	0.159	0.169	0.119
25	0.153	0.163	0.152	0.257	0.162	0.285	0.649	1.207	0.350	0.154	0.146	0.121
26	0.149	0.156	0.153	0.224	0.162	0.271	0.563	1.102	0.329	0.151	0.134	0.120
27	0.145	0.154	0.157	0.198	0.163	0.256	0.525	1.066	0.304	0.149	0.128	0.122
28	0.147	0.152	0.158	0.189	0.177	0.250	0.477	1.029	0.279	0.145	0.142	0.123
29	0.148	0.150	0.157*	0.185		0.246	0.446	1.009	0.262	0.151	0.132	0.115
30	0.145	0.148	0.159	0.179*		0.245	0.433	1.002	0.253	0.158	0.129	0.114
31	0.142		0.165	0.177*		0.242		0.972		0.150	0.127	

MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	4.218	4.764	4.757	5.755	4.778	8.219	11.343	48.077	13.491	5.551	4.374	3.707
TOTAL FLOW (cms days)	0.119	0.135	0.135	0.163	0.135	0.233	0.321	1.362	0.382	0.157	0.124	0.105
TOTAL DEPTH (in)	0.398	0.450	0.449	0.544	0.451	0.776	1.071	4.541	1.274	0.524	0.413	0.350
TOTAL DEPTH (cm)	1.012	1.143	1.141	1.381	1.146	1.972	2.721	11.534	3.237	1.332	1.049	0.889

ANNUAL SUMMARY:
Sum of Mean Daily Flow 119.033 cfs = 3.371 cms
Total Depth 11.243 in = 28.557 cm
Maximum Instantaneous Flow 3.918 cfs = 0.111 cms on May 15 at 17.75 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 4
WATERSHED AREA: 252 ACRES (101 HECTARES)

WATER YEAR 1976
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.076	0.122	0.321	0.167*	0.209*	0.194*	0.301	2.205	0.370	0.196	0.136	0.110
2	0.080	0.123	0.290	0.167*	0.214*	0.192*	0.299	2.686	0.365	0.195	0.125	0.109
3	0.080	0.123	0.255	0.167*	0.218*	0.192*	0.330	2.810	0.358	0.193	0.122	0.111
4	0.085	0.124	0.296	0.169*	0.220*	0.192*	0.477	2.878	0.344	0.192	0.122	0.112
5	0.084	0.126	0.352	0.170*	0.218*	0.195*	0.725	2.676	0.336	0.189	0.122	0.112
6	0.144	0.135	0.310	0.169*	0.216*	0.193*	0.985	2.518	0.326	0.185	0.118	0.126
7	0.171	0.157	0.454	0.168*	0.219*	0.192*	1.044	2.490	0.315	0.183	0.116	0.117
8	0.101	0.140	0.469	0.167*	0.220*	0.192*	1.414	2.476	0.299	0.180	0.126	0.113
9	0.098	0.134	0.424	0.169*	0.215*	0.192*	1.769	2.383	0.287	0.177	0.123	0.112
10	0.100	0.135	0.371	0.170*	0.210*	0.197*	1.749	2.277	0.309	0.173	0.114	0.110
11	0.159	0.128	0.341	0.172*	0.208*	0.208*	1.884	2.104	0.369	0.170	0.114	0.146
12	0.136	0.124	0.314	0.172*	0.205*	0.206*	1.954	1.798	0.305	0.167	0.113	0.125
13	0.118	0.124	0.280	0.174*	0.200*	0.205	1.830	1.605	0.305	0.154	0.111	0.116
14	0.110	0.124	0.253	0.176*	0.199*	0.215	1.751	1.472	0.275	0.148	0.110	0.112
15	0.106	0.164	0.244*	0.212*	0.194*	0.218	1.669	1.252	0.258	0.144	0.179	0.110
16	0.103	0.177	0.231*	0.237*	0.193*	0.220	1.462	1.101	0.287	0.138	0.148	0.127
17	0.101	0.153	0.219*	0.229*	0.190*	0.228	1.365	0.954	0.274	0.200	0.132	0.128
18	0.098	0.142	0.200*	0.221*	0.187*	0.245	1.322	0.870	0.256	0.276	0.133	0.129
19	0.096	0.134	0.195*	0.213*	0.184*	0.252	1.272	0.788	0.246	0.181	0.125	0.124
20	0.096	0.127	0.188*	0.205*	0.185*	0.249	1.245	0.715	0.233	0.169	0.112	0.119
21	0.124	0.124	0.189*	0.204*	0.184*	0.250	1.238	0.666	0.270	0.166	0.108	0.116
22	0.113	0.118	0.187*	0.205*	0.177*	0.251	1.231	0.599	0.239	0.147	0.118	0.116
23	0.104	0.117	0.180*	0.205*	0.176*	0.248	1.214	0.563	0.230	0.129	0.127	0.116
24	0.101	0.117	0.180*	0.206*	0.176*	0.245	1.396	0.526	0.228	0.141	0.118	0.112
25	0.099	0.120	0.176*	0.207*	0.177*	0.247	1.705	0.493	0.225	0.129	0.116	0.108
26	0.138	0.120	0.176*	0.206*	0.190*	0.244	1.615	0.462	0.229	0.124	0.124	0.106
27	0.116	0.121	0.173*	0.207*	0.201*	0.245	1.553	0.453	0.221	0.120	0.114	0.106
28	0.108	0.121	0.168*	0.207*	0.201*	0.240	1.528	0.447	0.214	0.118	0.110	0.099
29	0.103	0.119	0.168*	0.205*	0.196*	0.233	1.593	0.400	0.207	0.125	0.108	0.091
30	0.105	0.119	0.170*	0.204*		0.234	1.795	0.392	0.198	0.123	0.107	0.092
31	0.123		0.167*	0.205*		0.253		0.420		0.120	0.110	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	3.376	3.913	7.943	5.956	5.780	6.867	39.719	43.479	8.379	5.051	3.762	3.427
TOTAL FLOW (cms days)	0.096	0.111	0.225	0.169	0.164	0.194	1.125	1.231	0.237	0.143	0.107	0.097
TOTAL DEPTH (in)	0.319	0.370	0.750	0.563	0.546	0.649	3.751	4.107	0.791	0.477	0.355	0.324
TOTAL DEPTH (cm)	0.810	0.939	1.905	1.429	1.387	1.647	9.529	10.431	2.010	1.212	0.902	0.822

ANNUAL SUMMARY:
Sum of Mean Daily Flow 137.650 cfs = 3.898 cms
Total Depth 13.001 in = 33.023 cm
Maximum Instantaneous Flow 2.987 cfs = 0.085 cms on May 4 at 18.00 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 4
WATERSHED AREA: 252 ACRES (101 HECTARES)

WATER YEAR 1977
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.117	0.140	0.152	0.145	0.144	0.161	0.142	0.147	0.154	0.102	0.097	0.111
2	0.124	0.139	0.144	0.144	0.144	0.160	0.142	0.152	0.148	0.107	0.098	0.105
3	0.124	0.139	0.146	0.146	0.144	0.160	0.142	0.153	0.143	0.113	0.097	0.103
4	0.124	0.140	0.146	0.146	0.143	0.155	0.160	0.148	0.140	0.115	0.095	0.102
5	0.124	0.140	0.146	0.146	0.144	0.154	0.179	0.143	0.134	0.108	0.097	0.101
6	0.124	0.139	0.152	0.146	0.144	0.154	0.200	0.149	0.129	0.106	0.096	0.100
7	0.125	0.136	0.151	0.146	0.143	0.153	0.231	0.152	0.356	0.103	0.096	0.099
8	0.125	0.133	0.152	0.146	0.142	0.153	0.251	0.154	0.193	0.101	0.115	0.098
9	0.125	0.133	0.152	0.145	0.142	0.152	0.235	0.147	0.155	0.099	0.100	0.098
10	0.126	0.134	0.149	0.145	0.140	0.152	0.212	0.187	0.222	0.099	0.099	0.098
11	0.126	0.134	0.146	0.144	0.140	0.153	0.204	0.167	0.197	0.097	0.098	0.097
12	0.128	0.135	0.146	0.144	0.140	0.153	0.205	0.155	0.179	0.096	0.095	0.099
13	0.127	0.136	0.144	0.144	0.142	0.154	0.196	0.147	0.160	0.096	0.094	0.098
14	0.126	0.136	0.143	0.144	0.142	0.155	0.192	0.143	0.159	0.095	0.096	0.098
15	0.126	0.138	0.142	0.146	0.143	0.154	0.183	0.143	0.150	0.092	0.091	0.107
16	0.126	0.136	0.142	0.146	0.145	0.158	0.181	0.170	0.138	0.091	0.088	0.135
17	0.126	0.137	0.142	0.146	0.147	0.158	0.176	0.175	0.131	0.086	0.087	0.151
18	0.125	0.139	0.142	0.146	0.148	0.152	0.174	0.189	0.129	0.086	0.089	0.120
19	0.125	0.143	0.141	0.145	0.148	0.150	0.177	0.182	0.130	0.079	0.091	0.121
20	0.126	0.144	0.140	0.145	0.149	0.144	0.179	0.167	0.129	0.065	0.089	0.142
21	0.135	0.144	0.139	0.146	0.151	0.142	0.180	0.159	0.129	0.085	0.096	0.132
22	0.135	0.144	0.145	0.145	0.152	0.158	0.186	0.162	0.120	0.094	0.095	0.126
23	0.133	0.144	0.146	0.144	0.153	0.171	0.187	0.234	0.116	0.100	0.093	0.124
24	0.133	0.144	0.146	0.144	0.154	0.166	0.185	0.237	0.113	0.162	0.119	0.210
25	0.146	0.144	0.146	0.144	0.155	0.161	0.182	0.211	0.113	0.122	0.137	0.140
26	0.144	0.144	0.145	0.144	0.156	0.158	0.177	0.219	0.111	0.110	0.170	0.131
27	0.143	0.142	0.144	0.144	0.157	0.158	0.170	0.209	0.108	0.107	0.136	0.125
28	0.143	0.150	0.144	0.144	0.159	0.151	0.162	0.190	0.105	0.102	0.127	0.129
29	0.142	0.149	0.144	0.143		0.148	0.157	0.181	0.104	0.103	0.114	0.181
30	0.140	0.151	0.144	0.144		0.154	0.153	0.171	0.102	0.101	0.120	0.156
31	0.140		0.144	0.144		0.146		0.160		0.100	0.120	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	4.031	4.203	4.504	4.489	4.110	4.797	5.501	5.303	4.398	3.123	3.234	3.636
TOTAL FLOW (cms days)	0.114	0.119	0.128	0.127	0.116	0.136	0.156	0.150	0.125	0.088	0.092	0.103
TOTAL DEPTH (in)	0.381	0.397	0.425	0.424	0.388	0.453	0.520	0.501	0.415	0.295	0.305	0.343
TOTAL DEPTH (cm)	0.967	1.008	1.081	1.077	0.986	1.151	1.320	1.272	1.055	0.749	0.776	0.872

ANNUAL SUMMARY:
Sum of Mean Daily Flow 51.330 cfs = 1.454 cms
Total Depth 4.848 in = 12.314 cm
Maximum Instantaneous Flow 4.716 cfs = 0.134 cms on June 7 at 21.00 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 4
WATERSHED AREA: 252 ACRES (101 HECTARES)

WATER YEAR 1978
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.191	0.173	0.201	0.319	0.215	0.232	2.899*	1.380	0.681	0.249	0.147	0.123*
2	0.171	0.176	0.259	0.274	0.215	0.237*	2.287*	1.341	0.653	0.265	0.143	0.119*
3	0.165	0.167	0.269	0.266	0.225	0.236*	1.842*	1.290	0.633	0.264	0.141	0.117*
4	0.161	0.164	0.251	0.259	0.225	0.236*	1.585*	1.232	0.612	0.257	0.134	0.122*
5	0.159	0.182	0.234	0.248	0.231	0.247*	1.377*	1.142	0.583	0.253	0.129	0.129*
6	0.156	0.175	0.231	0.233	0.247	0.269*	1.254*	1.085	0.536	0.273	0.127	0.202*
7	0.159	0.167	0.228	0.224	0.241	0.271*	1.182*	1.015	0.511	0.246	0.124	0.199*
8	0.159	0.161	0.222	0.219	0.245	0.317*	1.123*	0.977	0.482	0.239	0.126	0.180*
9	0.159	0.159	0.213	0.222	0.239	0.417*	1.129*	0.976	0.459	0.226	0.125	0.135*
10	0.158	0.159	0.210	0.224	0.236	0.442*	1.255*	1.002	0.496	0.217	0.128	0.158*
11	0.157	0.159	0.207	0.225	0.232	0.472*	1.388*	1.047	0.467	0.220	0.129	0.102*
12	0.157	0.155	0.206	0.230	0.229	0.474*	1.352*	0.983	0.437	0.233	0.122	0.116*
13	0.155	0.158	0.226	0.230	0.215	0.425*	1.277*	0.934	0.413	0.233	0.205	0.117*
14	0.155	0.160	0.846	0.231	0.215	0.381*	1.223*	0.913	0.394	0.221	0.160	0.114*
15	0.154	0.237	1.546	0.234	0.218	0.348*	1.282*	0.936	0.374	0.214	0.165*	0.111*
16	0.153	0.197	0.676	0.232	0.217	0.352*	1.452*	0.866	0.349	0.209	0.179*	0.119*
17	0.153	0.181	0.483	0.233	0.219	0.424*	1.306*	0.806	0.330	0.210	0.161*	0.119*
18	0.152	0.170	0.382	0.232	0.217	0.619*	1.223*	0.753	0.335	0.207	0.140*	0.116*
19	0.152	0.164	0.334	0.228	0.218	0.846*	1.207*	0.710	0.319	0.207	0.133*	0.116*
20	0.151	0.162	0.300	0.228	0.217	1.007*	1.241*	0.675	0.291	0.199	0.129*	0.124*
21	0.152	0.184	0.287	0.230	0.214	1.179*	1.145*	0.646	0.272*	0.196	0.120*	0.123*
22	0.150	0.178	0.274	0.233	0.206	1.484*	1.040*	0.626	0.268*	0.193	0.128*	0.131*
23	0.148	0.174	0.261	0.233	0.201	1.767*	0.993*	0.635	0.261*	0.190	0.119*	0.144*
24	0.149	0.182	0.252	0.232	0.205	1.560*	0.998*	0.640	0.272	0.176	0.122*	0.144*
25	0.151	0.267	0.242	0.222	0.219	1.381*	1.104*	0.605	0.320	0.169	0.137*	0.142*
26	0.167	0.321	0.235	0.221	0.225	1.567*	1.376	0.717	0.273	0.168	0.138*	0.152*
27	0.157	0.236	0.231	0.220	0.235	1.965*	1.549	0.820	0.258	0.164	0.136*	0.167*
28	0.156	0.221	0.226	0.218	0.234	2.396*	1.505	0.784	0.251	0.164	0.131*	0.168*
29	0.156	0.217	0.222	0.218		2.735*	1.461	0.754	0.243	0.157	0.131*	0.168*
30	0.181	0.206	0.230	0.218		3.097*	1.415	0.727	0.269	0.153	0.132*	0.167*
31	0.175		0.224	0.218		3.004*		0.704		0.149	0.132*	
MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	4.921	5.615	10.210	7.253	6.255	30.387	41.471	27.721	12.044	6.521	4.276	4.144
TOTAL FLOW (cms days)	0.139	0.159	0.289	0.205	0.177	0.861	1.174	0.785	0.341	0.185	0.121	0.117
TOTAL DEPTH (in)	0.465	0.530	0.964	0.685	0.591	2.870	3.917	2.618	1.138	0.616	0.404	0.391
TOTAL DEPTH (cm)	1.181	1.347	2.449	1.740	1.501	7.290	9.949	6.650	2.890	1.564	1.026	0.994

ANNUAL SUMMARY:
Sum of Mean Daily Flow 160.816 cfs = 4.554 cms
Total Depth 15.189 in = 38.581 cm
Maximum Instantaneous Flow 3.224 cfs = 0.091 cms on March 30 at 17.89 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 4
WATERSHED AREA: 252 ACRES (101 HECTARES)

WATER YEAR 1979
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.052*	0.051	0.059	0.052*	0.057	0.054	0.154*	0.419	0.127*	0.038*	0.021	0.034
2	0.053*	0.050	0.056	0.053*	0.056	0.075	0.140*	0.402	0.123*	0.037*	0.021	0.032
3	0.053*	0.050	0.053	0.053*	0.055	0.066	0.130*	0.391	0.120*	0.037*	0.022	0.030
4	0.052*	0.049	0.147	0.053*	0.055	0.057	0.139*	0.387	0.115*	0.037*	0.021	0.029
5	0.051*	0.047	0.090	0.053*	0.053	0.053	0.188*	0.380*	0.109*	0.037*	0.020	0.028
6	0.051*	0.048	0.086*	0.053*	0.052	0.053	0.247*	0.364*	0.103*	0.037*	0.019	0.027
7	0.050*	0.050	0.075*	0.053*	0.052*	0.057	0.252	0.352*	0.100*	0.037*	0.018	0.025
8	0.049*	0.058	0.074*	0.053*	0.052*	0.065	0.298	0.346*	0.096*	0.037*	0.022	0.025
9	0.048*	0.055	0.074	0.053*	0.053*	0.090	0.351	0.334*	0.091*	0.036*	0.019	0.025
10	0.048*	0.051	0.074	0.053*	0.054*	0.138	0.301	0.311*	0.084*	0.036*	0.016	0.026
11	0.048*	0.051	0.072*	0.053*	0.055*	0.155	0.255	0.328*	0.076*	0.032	0.017	0.024
12	0.096*	0.054	0.070*	0.053*	0.056*	0.173	0.224	0.337*	0.068*	0.036	0.020	0.022
13	0.054	0.053	0.069*	0.054*	0.057*	0.166*	0.211	0.316*	0.063*	0.036	0.051	0.022
14	0.055	0.055	0.067*	0.054*	0.058*	0.162*	0.203	0.299*	0.059*	0.035	0.044	0.021
15	0.054	0.057	0.065*	0.055*	0.058*	0.160*	0.258	0.279*	0.054*	0.034	0.036	0.021
16	0.054	0.060	0.064*	0.057*	0.058*	0.159*	0.327	0.268*	0.050*	0.033	0.032	0.021
17	0.054	0.060	0.063*	0.057*	0.059*	0.159*	0.456	0.247*	0.052*	0.032	0.043	0.021
18	0.052	0.060	0.061*	0.057*	0.060*	0.160*	0.381	0.232*	0.055*	0.032	0.042	0.020
19	0.049	0.057	0.060*	0.058*	0.061*	0.160*	0.319	0.217*	0.054*	0.031	0.040	0.019
20	0.050	0.056	0.054*	0.057*	0.061*	0.160*	0.288	0.202*	0.048*	0.029	0.033	0.020
21	0.050	0.056	0.050	0.056*	0.061*	0.159*	0.287*	0.194*	0.037*	0.028	0.032	0.020
22	0.051	0.059	0.052	0.056*	0.061*	0.159*	0.300*	0.187*	0.041*	0.034	0.029	0.020
23	0.052	0.056	0.052	0.056*	0.061*	0.171*	0.328*	0.180*	0.041*	0.031	0.047	0.020
24	0.052	0.054	0.054	0.055*	0.061*	0.187*	0.340*	0.176*	0.040*	0.027	0.036	0.022
25	0.054	0.054	0.051	0.054*	0.061*	0.196*	0.331*	0.170*	0.040*	0.027	0.029	0.037
26	0.054	0.053	0.050	0.054*	0.062*	0.197*	0.347*	0.159*	0.039*	0.025	0.028	0.038
27	0.051	0.055	0.050	0.054*	0.061*	0.226*	0.370	0.153*	0.039*	0.025	0.034	0.031
28	0.052	0.059	0.050*	0.054*	0.059	0.249*	0.404	0.148*	0.038*	0.025	0.032	0.029
29	0.052	0.059	0.050*	0.055*		0.232*	0.427	0.142*	0.038*	0.025	0.029	0.028
30	0.052	0.062	0.051*	0.056*		0.194*	0.435	0.137*	0.038*	0.024	0.035	0.027
31	0.052		0.052*	0.058		0.169*		0.131*		0.023	0.040	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	1.645	1.639	1.994	1.691	1.608	4.465	8.689	8.186	2.038	0.993	0.926	0.764
TOTAL FLOW (cms days)	0.047	0.046	0.056	0.048	0.046	0.126	0.246	0.232	0.058	0.028	0.026	0.022
TOTAL DEPTH (in)	0.155	0.155	0.188	0.160	0.152	0.422	0.821	0.773	0.193	0.094	0.087	0.072
TOTAL DEPTH (cm)	0.395	0.393	0.478	0.406	0.386	1.071	2.084	1.964	0.489	0.238	0.222	0.183

ANNUAL SUMMARY:
Sum of Mean Daily Flow 34.638 cfs = 0.981 cms
Total Depth 3.272 in = 8.310 cm
Maximum Instantaneous Flow 0.574 cfs = 0.016 cms on April 17 at 04.45 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 4
WATERSHED AREA: 252 ACRES (101 HECTARES)

WATER YEAR 1980
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.043	0.069	0.072	0.083	0.106*	0.318	0.214	1.063	0.422	0.154	0.080	0.062
2	0.042	0.069	0.078	0.083	0.105*	0.300	0.213	0.968	0.432*	0.175	0.081	0.078
3	0.042	0.069	0.114	0.082	0.103*	0.291	0.212	0.872	0.404*	0.152	0.081	0.063
4	0.042	0.074	0.094	0.082*	0.102*	0.295	0.212	0.785	0.395*	0.136	0.082*	0.055
5	0.041	0.077	0.086	0.082*	0.100*	0.285	0.231	0.700	0.459*	0.127	0.084*	0.054
6	0.041	0.073	0.083	0.082*	0.098*	0.272	0.232	0.723	0.445*	0.121	0.078*	0.053
7	0.039	0.073	0.082	0.083*	0.097*	0.249	0.236	0.648	0.427*	0.118	0.074*	0.051
8	0.039	0.071	0.082	0.083*	0.097	0.239	0.254	0.619	0.402*	0.119	0.073	0.051
9	0.039	0.071	0.081	0.086*	0.097	0.229	0.277	0.623	0.377*	0.115	0.070	0.049
10	0.039	0.071	0.090	0.089*	0.096	0.224	0.282	0.590	0.355	0.109	0.066	0.102
11	0.039	0.070	0.075	0.090	0.095	0.217	0.286	0.534	0.356	0.106	0.062	0.096
12	0.041	0.069	0.077	0.141	0.095	0.209	0.325	0.481	0.412	0.104	0.057	0.070
13	0.040	0.069	0.079	0.219	0.095	0.208	0.474	0.457	0.390	0.101	0.054	0.092
14	0.038	0.066	0.077	0.301	0.094	0.250	0.733*	0.435	0.397	0.109	0.052	0.075
15	0.098	0.065	0.077	0.295	0.094	0.218	0.904*	0.435	0.364*	0.104	0.084	0.066
16	0.060	0.065	0.077	0.224	0.096	0.208	0.931*	0.458	0.301*	0.090	0.063	0.062
17	0.062	0.069	0.075	0.188	0.108	0.206	1.185	0.410	0.286	0.088	0.054	0.064
18	0.106	0.069	0.075	0.165	0.174*	0.205	1.692	0.397	0.268	0.086	0.060	0.086
19	0.149	0.065	0.076	0.149	0.239*	0.200	2.051*	0.380	0.257	0.084	0.060	0.078
20	0.089	0.065	0.076	0.141	0.247*	0.200	2.439	0.372	0.251	0.087	0.059	0.089
21	0.081	0.063	0.076	0.135	0.238*	0.198	2.481	0.359	0.245	0.084	0.058*	0.084
22	0.090	0.062	0.075	0.130	0.215*	0.197	2.379	0.353	0.241	0.082	0.059*	0.075
23	0.100	0.063	0.073	0.126	0.200*	0.198	2.327	0.377	0.245	0.078	0.055*	0.076
24	0.082	0.064	0.076	0.123	0.186*	0.199	2.300	0.376	0.227	0.078	0.052*	0.074
25	0.105	0.066	0.082	0.117*	0.178	0.201	2.041	0.426	0.205	0.075	0.052*	0.073
26	0.091	0.066	0.081	0.113*	0.179*	0.204	1.800	0.436	0.200	0.072	0.054*	0.073
27	0.077	0.065	0.080	0.112*	0.212	0.212	1.734	0.441	0.192	0.066	0.056*	0.072
28	0.075	0.064*	0.080	0.110*	0.290	0.216	1.670	0.435	0.180	0.064	0.059	0.072
29	0.071	0.067*	0.080	0.108*	0.313	0.217	1.484	0.424	0.167	0.077	0.059	0.073
30	0.069	0.070*	0.077	0.106*		0.216	1.214	0.412	0.166	0.078	0.060	0.072
31	0.070		0.079	0.107*		0.214		0.399		0.079	0.061	
MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	2.036	2.038	2.486	4.034	4.349	7.094	32.814	16.387	9.468	3.118	1.999	2.142
TOTAL FLOW (cms days)	0.058	0.058	0.070	0.114	0.123	0.201	0.929	0.464	0.268	0.088	0.057	0.061
TOTAL DEPTH (in)	0.192	0.193	0.235	0.381	0.411	0.670	3.099	1.548	0.894	0.294	0.189	0.202
TOTAL DEPTH (cm)	0.488	0.489	0.596	0.968	1.043	1.702	7.872	3.931	2.271	0.748	0.480	0.514

ANNUAL SUMMARY:
Sum of Mean Daily Flow 87.965 cfs = 2.491 cms
Total Depth 8.308 in = 21.103 cm
Maximum Instantaneous Flow 2.770 cfs = 0.078 cms on April 20 at 18.71 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 5
WATERSHED AREA: 270 ACRES (109 HECTARES)

WATER YEAR 1968
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.116	0.078	0.264	0.184*	0.167*	0.531	0.920	0.542	0.193	0.134	0.079	0.104
2	0.145	0.074	0.283	0.179*	0.158*	0.549	1.053	0.528	0.177	0.130	0.080	0.106
3	0.182	0.075*	0.292	0.172*	0.161*	0.576	1.088	0.500	0.171	0.126	0.078	0.103
4	0.101	0.086*	0.332	0.166*	0.166*	0.621	1.060	0.480	0.172	0.120	0.072	0.097
5	0.100	0.086*	0.367	0.161*	0.168*	0.728	1.202	0.473	0.180	0.118	0.071	0.097
6	0.099	0.086*	0.368	0.156*	0.192*	0.782	1.166	0.445	0.204	0.118	0.071	0.098
7	0.092	0.086*	0.373	0.151*	0.256*	0.739	1.070	0.420	0.201	0.115	0.072	0.096
8	0.086	0.201	0.404	0.145*	0.304*	0.691	0.985	0.396	0.185	0.114	0.082	0.095
9	0.086	0.256	0.409	0.139*	0.333*	0.638	0.947	0.379	0.183	0.116	0.088	0.094
10	0.082	0.296	0.422	0.134*	0.369*	0.576	0.978	0.365	0.188	0.116	0.126	0.094
11	0.079	0.348	0.453	0.130*	0.417*	0.534	1.071	0.356	0.172	0.110	0.099	0.092
12	0.082	0.337	0.443*	0.126*	0.460*	0.514	1.056	0.371	0.170	0.113	0.093	0.090
13	0.078	0.317	0.416*	0.121*	0.433*	0.512	0.963	0.375	0.167	0.115	0.106	0.090
14	0.078	0.298	0.396*	0.117*	0.391*	0.494	0.918	0.345	0.162	0.110	0.194	0.102
15	0.078	0.223*	0.373*	0.113*	0.371*	0.475	0.879	0.309	0.148	0.107	0.212*	0.112
16	0.078	0.102	0.354*	0.109*	0.409	0.475	0.814	0.296	0.140	0.105	0.184*	0.108
17	0.078	0.103	0.337*	0.105*	0.403	0.475	0.748	0.268	0.137	0.104	0.179*	0.102
18	0.078	0.115	0.319*	0.102*	0.412	0.475	0.702	0.245	0.136	0.093	0.172*	0.100
19	0.078	0.134	0.302*	0.099*	0.850	0.459	0.665	0.228	0.154	0.093	0.145*	0.100
20	0.078	0.137	0.287*	0.096*	1.640	0.451	0.616	0.253	0.159	0.094	0.156*	0.117
21	0.084	0.144	0.274*	0.093*	1.179	0.450	0.586	0.240	0.154	0.112	0.153	0.130
22	0.091	0.152	0.262*	0.089*	0.878	0.450	0.557	0.229	0.154	0.117	0.150	0.125
23	0.094	0.163	0.252*	0.124*	0.981	0.483	0.530	0.229	0.171	0.117	0.147	0.117
24	0.090	0.187	0.243*	0.178*	1.048	0.543	0.528	0.229	0.153	0.111	0.131	0.111
25	0.082	0.198	0.235*	0.203*	0.878	0.617	0.522	0.280	0.145	0.106	0.119	0.107
26	0.078	0.206	0.227*	0.212*	0.733	0.682	0.515	0.282	0.140	0.104	0.113	0.103
27	0.091	0.206	0.219*	0.204*	0.623	0.681	0.493	0.261	0.136	0.104	0.113	0.102
28	0.181	0.213	0.212*	0.198*	0.561	0.689	0.495	0.239	0.135	0.105	0.110	0.100
29	0.092	0.233	0.204*	0.191*	0.521	0.741	0.513	0.215	0.138	0.102	0.107	0.097
30	0.086	0.248	0.198*	0.184*		0.837	0.534	0.205	0.139	0.088	0.105	0.094
31	0.082		0.191*	0.179*		0.869		0.200		0.080	0.104	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	2.921	5.386	9.711	4.560	15.464	18.338	24.174	10.184	4.867	3.396	3.709	3.081
TOTAL FLOW (cms days)	0.083	0.153	0.275	0.129	0.438	0.519	0.685	0.288	0.138	0.096	0.105	0.087
TOTAL DEPTH (in)	0.257	0.475	0.856	0.402	1.363	1.617	2.131	0.898	0.429	0.299	0.327	0.272
TOTAL DEPTH (cm)	0.654	1.206	2.174	1.021	3.462	4.106	5.413	2.280	1.090	0.760	0.830	0.690

ANNUAL SUMMARY:
Sum of Mean Daily Flow 105.791 cfs = 2.996 cms
Total Depth 9.326 in = 23.688 cm
Maximum Instantaneous Flow 2.104 cfs = 0.060 cms on February 20 at 02.50 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 5
WATERSHED AREA: 270 ACRES (109 HECTARES)

WATER YEAR 1969
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.094	0.104	0.125	0.092	0.229*	0.153	1.576	1.777	0.348	0.213*	0.115	0.093
2	0.094	0.103	0.124	0.092	0.221*	0.153	1.745	1.623	0.333	0.206*	0.114	0.092
3	0.094	0.120	0.124	0.093	0.213*	0.153	1.967	1.551	0.312	0.198*	0.113	0.096
4	0.094	0.124	0.128	0.093	0.206*	0.159	1.868	1.556	0.308	0.193*	0.114*	0.099
5	0.094	0.115	0.130	0.115	0.198*	0.166	2.224	1.589	0.309	0.186*	0.114*	0.098
6	0.094	0.115	0.125	0.131	0.193*	0.166	3.063	1.655	0.295	0.179*	0.109	0.097
7	0.094	0.114	0.129	0.131	0.186*	0.162	2.819	1.684	0.275	0.173*	0.108	0.096
8	0.094	0.114	0.117	0.128	0.179*	0.156	2.339	1.667	0.280	0.168*	0.107	0.098
9	0.C94	0.180	0.117	0.126	0.173*	0.156	2.368	1.565	0.283	0.162	0.106	0.097
10	0.094	0.143	0.128	0.124	0.171*	0.156	2.756	1.425	0.270	0.156	0.106	0.098
11	0.121	0.162	0.156	0.123	0.173*	0.156	3.071	1.217	0.250	0.151	0.111	0.101
12	0.146	0.271	0.133	0.123	0.177*	0.154	3.271	1.059	0.247	0.146	0.110	0.101
13	0.144	0.185	0.216	0.149	0.180*	0.152	3.361	0.956	0.241	0.141	0.105	0.102
14	0.132	0.151	0.196	0.156	0.177*	0.151	3.164	0.994	0.233	0.137	0.105	0.101
15	0.125	0.146	0.113	0.151	0.171*	0.151	2.908	0.873	0.227	0.132	0.103	0.100
16	0.121	0.136	0.127	0.145	0.166*	0.156	2.897	0.756	0.220	0.128	0.097	0.099
17	0.116	0.132	0.120	0.142	0.161*	0.165	2.956	0.679	0.212	0.130	0.101	0.096
18	0.114	0.145	0.116	0.151*	0.154*	0.178	3.721	0.641	0.207	0.139*	0.101	0.096
19	0.111	0.149	0.115	0.168*	0.154	0.180	3.518	0.624	0.203*	0.135	0.100	0.116
20	0.120	0.147	0.103	0.173*	0.156	0.182	3.138	0.615	0.197*	0.124*	0.101	0.149
21	0.120	0.145	0.092	0.265*	0.156	0.206	3.214	0.592	0.190*	0.123*	0.099	0.122
22	0.115	0.184	0.092	0.358*	0.154	0.221	3.773	0.545	0.186*	0.119*	0.099	0.115
23	0.112	0.177	0.097	0.339*	0.153	0.239	4.253	0.525	0.179*	0.122*	0.101*	0.114
24	0.110	0.162	0.102	0.321*	0.153	0.246	4.289	0.500	0.220*	0.122	0.098	0.115
25	0.108	0.153	0.104	0.306*	0.154	0.270	3.380	0.474	0.265*	0.131*	0.098	0.114
26	0.105	0.146	0.104	0.291*	0.156	0.325	2.789	0.450	0.253*	0.126	0.096	0.117
27	0.104	0.144	0.104	0.276*	0.156	0.431	2.394	0.428	0.245*	0.124	0.093	0.117
28	0.104	0.138	0.103	0.264*	0.154	0.473	2.218	0.403	0.237*	0.124	0.093	0.115
29	0.104	0.136	0.101	0.253*		0.634	2.119	0.381	0.229*	0.120	0.093	0.114
30	0.112	0.132	0.096	0.245*		0.945	1.924	0.379	0.221*	0.118	0.093	0.114
31	0.106		0.093	0.237*		1.378		0.365		0.116	0.093	
MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	3.396	4.373	3.729	5.758	4.874	8.573	85.083	29.548	7.474	4.541	3.195	3.182
TOTAL FLOW (cms days)	0.096	0.124	0.106	0.163	0.138	0.243	2.410	0.837	0.212	0.129	0.090	0.090
TOTAL DEPTH (in)	0.299	0.386	0.329	0.508	0.430	0.756	7.500	2.605	0.659	0.400	0.282	0.280
TOTAL DEPTH (cm)	0.760	0.979	0.835	1.289	1.091	1.920	19.051	6.616	1.673	1.017	0.715	0.712

ANNUAL SUMMARY:
Sum of Mean Daily Flow 163.726 cfs = 4.637 cms
Total Depth 14.433 in = 36.660 cm
Maximum Instantaneous Flow 4.815 cfs = 0.136 cms on April 23 at 23.25 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 5
WATERSHED AREA: 270 ACRES (109 HECTARES)

WATER YEAR 1970
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.116	0.142	0.099	0.473	0.448*	0.374	0.518	0.890	0.761	0.294	0.123	0.107
2	0.156	0.141	0.080	0.486	0.426*	0.398	0.501	1.240	0.698	0.272	0.121	0.106
3	0.140	0.145	0.073	0.236	0.405*	0.392	0.499	1.847	0.653	0.267	0.121	0.104
4	0.137	0.148	0.072	0.219	0.382*	0.378	0.499	2.740	0.612	0.254	0.119	0.137
5	0.130	0.159	0.068	0.147	0.362*	0.352	0.561	4.356	0.565	0.245	0.125	0.136
6	0.126	0.184	0.058	0.092	0.415*	0.340	0.864	5.277	0.515	0.235	0.122	0.128
7	0.126	0.169	0.067	0.102	0.468*	0.336	1.235	5.179	0.506	0.238	0.117	0.128
8	0.156	0.159	0.068	0.121	0.443*	0.354	1.194	4.843	0.483	0.228	0.114	0.184
9	0.159	0.153	0.070	0.108*	0.419*	0.354	1.196	4.845	0.499	0.220	0.111	0.128
10	0.145	0.151	0.070	0.115*	0.398*	0.354	1.652	4.405	0.464	0.232	0.110	0.127
11	0.142	0.151	0.073	0.111*	0.378*	0.354	1.814	3.710	0.414	0.227	0.118	0.114
12	0.141	0.150	0.082	0.107*	0.358*	0.354	1.621	3.221	0.398	0.206	0.122	0.118
13	0.136	0.148	0.096	0.104*	0.316	0.354	1.449	2.788	0.398	0.195	0.119	0.117
14	0.132	0.148	0.093	0.100*	0.293	0.371	1.300	2.502	0.446	0.189	0.122	0.117
15	0.132	0.148	0.090	0.096*	0.279	0.417	1.179	2.438	0.417	0.176	0.118	0.117
16	0.132	0.148	0.088	0.094*	0.272	0.440	1.096	2.637	0.407	0.175	0.115	0.117
17	0.132	0.143	0.086	0.091*	0.378	0.450	1.032	3.051	0.377	0.191	0.114	0.117
18	0.132	0.140	0.086	0.088*	0.345	0.450	1.013	3.398	0.357	0.170	0.109	0.118
19	0.132	0.140	0.087	0.084*	0.330	0.442	1.020	3.398	0.337	0.164	0.107	0.161
20	0.132	0.137	0.094	0.082*	0.322	0.430	0.998	3.023	0.303	0.163	0.108	0.153
21	0.132	0.137	0.197	0.079*	0.311	0.426	0.949	2.685	0.290	0.165	0.107	0.136
22	0.131	0.135	0.144	0.076*	0.306	0.426	0.909	2.199	0.290	0.158	0.108	0.137
23	0.130	0.138	0.118	0.073*	0.306	0.430	0.884	2.104	0.288	0.152	0.109	0.139
24	0.130	0.136	0.108	0.304*	0.306	0.445	0.879	1.524	0.273	0.149	0.109	0.136
25	0.130	0.128	0.105	0.652*	0.306	0.464	0.860	1.375	0.269	0.142	0.107	0.134
26	0.130	0.125	0.107	0.618*	0.309	0.483	0.839	1.258	0.262	0.137	0.106	0.132
27	0.135	0.122	0.100	0.588*	0.317	0.491	0.810	1.173	0.286*	0.147	0.104	0.128
28	0.154	0.111	0.204	0.556*	0.327	0.534	0.808	1.075	0.219	0.172	0.103	0.128
29	0.146	0.098	0.342	0.526*		0.537	0.808	0.987	0.301	0.166	0.103	0.126
30	0.145	0.098	0.447	0.499*		0.529	0.808	0.920	0.281	0.133	0.105	0.123
31	0.144		0.382	0.473*		0.524		0.857		0.122	0.108	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	4.244	4.232	3.856	7.502	9.922	12.983	29.797	81.944	12.368	5.983	3.503	3.855
TOTAL FLOW (cms days)	0.120	0.120	0.109	0.212	0.281	0.368	0.844	2.321	0.350	0.169	0.099	0.109
TOTAL DEPTH (in)	0.374	0.373	0.340	0.661	0.875	1.145	2.627	7.224	1.090	0.527	0.309	0.340
TOTAL DEPTH (cm)	0.950	0.948	0.863	1.680	2.222	2.907	6.672	18.348	2.769	1.340	0.784	0.863

ANNUAL SUMMARY:
Sum of Mean Daily Flow 180.190 cfs = 5.103 cms
Total Depth 15.885 in = 40.347 cm
Maximum Instantaneous Flow 5.553 cfs = 0.157 cms on May 6 at 15.50 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 5
WATERSHED AREA: 270 ACRES (109 HECTARES)

WATER YEAR 1971
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.121	0.146	0.268*	0.317	0.371	0.371	0.907	5.107	0.733	0.428	0.200	0.165
2	0.121	0.147	0.273*	0.313	0.396	0.367	0.967	6.264	0.726	0.407	0.201	0.176
3	0.121	0.147	0.256*	0.325	0.402	0.367	1.055	7.084	0.700	0.395	0.203	0.171
4	0.124	0.146	0.281*	0.362	0.402	0.362	1.198	6.960	0.668	0.381	0.194	0.169
5	0.126	0.195	0.272	0.372	0.391	0.350	1.459	7.307	0.638	0.364	0.188	0.166
6	0.126	0.232	0.294*	0.387	0.380	0.339	1.882	6.727	0.613	0.353	0.192	0.173
7	0.126	0.235	0.320	0.396	0.382	0.337	3.063*	6.451	0.588	0.341	0.194	0.202
8	0.126	0.216	0.346	0.398	0.384	0.331	3.570*	5.687	0.567	0.331	0.189	0.177
9	0.135	0.280	0.346	0.396	0.384	0.319	3.608	5.203	0.546	0.322	0.181	0.171
10	0.150	0.274	0.346	0.298	0.386	0.313	3.591	4.676	0.536	0.314	0.175	0.164
11	0.131*	0.229	0.343	0.201	0.356	0.327	3.343	4.287	0.539*	0.309	0.177	0.160
12	0.125	0.233	0.319*	0.249	0.346	0.322	2.951	3.876	0.576	0.306	0.174	0.158
13	0.126	0.216	0.386	0.312	0.346	0.337	2.740	3.675	0.619	0.298	0.174	0.156
14	0.127	0.200	0.421	0.355	0.350	0.324	2.970	3.051	0.581	0.294	0.175	0.152
15	0.130	0.195	0.329	0.346	0.373	0.307	3.848*	2.520	0.527	0.289	0.174	0.153
16	0.133	0.195	0.307*	0.327	0.384	0.302	4.241	2.294	0.405	0.277	0.176	0.159
17	0.132	0.195	0.295	0.352	0.390	0.298	4.671	1.952	0.393	0.269	0.181	0.161
18	0.129	0.203	0.275*	0.343	0.393	0.306	4.605*	1.706	0.392	0.263	0.176	0.161
19	0.137	0.209	0.267*	0.333	0.393	0.308	4.902	1.530	0.379	0.280	0.170	0.159
20	0.145	0.209	0.243	0.339	0.393	0.311	5.662	1.391	0.365	0.288	0.165	0.158
21	0.151	0.203	0.276	0.344	0.393	0.325	6.577	1.266	0.357	0.265	0.169	0.156
22	0.160	0.185	0.283	0.367	0.390	0.311	6.508	1.167	0.358	0.255	0.170	0.153
23	0.155*	0.243	0.284	0.399	0.382	0.330	5.443	1.112	0.358	0.238	0.167	0.152
24	0.166	0.828	0.287	0.395	0.380	0.398	4.777	1.055	0.357	0.229	0.166	0.151
25	0.153	0.742	0.287	0.367	0.380	0.438	4.400	0.999	0.390	0.224	0.166	0.150
26	0.145	0.441	0.279	0.375	0.380	0.538	4.397	0.942	0.631	0.219	0.170	0.150
27	0.138	0.346	0.276	0.375	0.380	0.646	4.360	0.889	0.551	0.215	0.170	0.152
28	0.137	0.317	0.304*	0.373	0.379	0.659	4.355	0.849	0.537	0.211	0.178	0.154
29	0.140	0.294*	0.337*	0.369		0.682	4.504	0.818	0.484	0.207	0.169	0.190
30	0.146	0.281*	0.329*	0.354		0.791	4.622	0.787	0.449	0.205	0.173	0.185
31	0.146		0.322*	0.348		0.877		0.762		0.203	0.168	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	4.226	7.981	9.450	10.787	10.669	12.594	111.175	98.395	15.565	8.982	5.524	4.903
TOTAL FLOW (cms days)	0.120	0.226	0.268	0.305	0.302	0.357	3.148	2.787	0.441	0.254	0.156	0.139
TOTAL DEPTH (in)	0.373	0.704	0.833	0.951	0.940	1.110	9.801	8.674	1.372	0.792	0.487	0.432
TOTAL DEPTH (cm)	0.946	1.787	2.116	2.415	2.389	2.820	24.893	22.032	3.485	2.011	1.237	1.098

ANNUAL SUMMARY:
Sum of Mean Daily Flow 300.248 cfs = 8.503 cms
Total Depth 26.468 in = 67.229 cm
Maximum Instantaneous Flow 7.585 cfs = 0.215 cms on May 5 at 23.25 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 5
WATERSHED AREA: 270 ACRES (109 HECTARES)

WATER YEAR 1972
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.176	0.190	0.168	0.144	0.152	0.434	0.818	2.198	0.566*	0.324	0.170	0.146
2	0.161	0.176	0.159	0.148	0.150*	0.381	0.989	2.179	0.515	0.310	0.172	0.145
3	0.150	0.173	0.168	0.150	0.144*	0.490	1.165	2.329	0.500	0.306	0.165	0.143
4	0.150	0.178	0.167	0.243	0.149	0.381	1.255	2.733	0.477	0.289	0.162	0.141
5	0.150	0.170	0.167	0.145	0.147	0.335	1.541	2.971	0.440	0.278	0.158	0.183
6	0.151	0.163	0.167	0.141	0.151	0.321	2.185	3.038	0.417	0.271	0.155	0.183
7	0.148	0.170	0.163	0.141	0.147	0.314	2.387	3.038	0.550	0.262	0.154	0.165
8	0.146	0.161	0.163	0.141	0.144	0.306	2.130	3.285	0.586	0.254	0.152	0.156
9	0.146	0.161	0.163	0.141	0.144	0.334	2.057	2.900	0.793	0.248	0.155	0.148
10	0.146	0.162	0.158	0.141	0.144	0.557	1.980	2.543	0.869	0.246	0.157	0.148
11	0.146	0.181	0.154	0.141	0.144	0.869	1.875	2.272	0.778	0.240	0.155	0.152
12	0.146	0.194	0.153	0.144	0.144	0.946	1.849	2.226	0.700	0.230	0.156	0.156
13	0.146	0.195	0.156	0.144	0.144	1.122	1.704	2.113	0.648	0.222	0.154	0.156
14	0.147	0.189	0.156	0.139	0.144	1.160	1.593	2.088	0.604	0.214	0.177	0.154
15	0.153	0.182	0.154	0.139	0.139	1.134	1.508	2.119	0.575	0.209	0.187	0.153
16	0.158	0.175	0.152	0.139	0.133	1.332	1.516	2.005	0.556	0.204	0.164	0.152
17	0.158	0.171	0.156	0.134	0.133	1.740	1.524	1.901	0.534	0.200	0.159	0.152
18	0.158	0.169	0.157	0.132	0.137	2.252	1.497	1.697	0.504	0.210	0.152	0.150
19	0.171	0.163	0.154	0.157	0.137	2.044	1.479	1.536	0.485	0.211	0.148	0.156
20	0.203	0.163	0.153	0.159	0.143	1.575	1.538	1.440	0.469	0.214	0.151	0.160
21	0.180	0.163	0.153	0.237	0.161	1.497	1.752	1.282	0.453	0.210	0.154	0.154
22	0.171	0.163	0.191	0.223	0.161	1.705	1.912	1.195	0.437	0.207	0.147	0.151
23	0.168	0.163	0.205	0.191	0.157	2.258	2.048	1.102	0.426	0.196	0.148	0.151
24	0.176	0.165	0.172	0.173	0.153	1.936	2.252	0.971	0.419	0.183	0.147	0.158
25	0.183	0.166	0.168	0.170*	0.147	1.632	2.223	0.889	0.447	0.179	0.146	0.164
26	0.183	0.219	0.166	0.166*	0.141	1.332	2.101	0.814	0.405	0.184	0.144	0.159
27	0.184	0.177	0.159	0.159*	0.225	1.114	2.262	0.759	0.377	0.187	0.143	0.164
28	0.176	0.176	0.153	0.153*	0.446	0.980	2.744	0.719	0.354	0.180	0.174	0.160
29	0.194	0.178	0.150	0.148*	0.675	0.859	2.880	0.683	0.341	0.173	0.170	0.160
30	0.169	0.176	0.141	0.151		0.784	2.415	0.643	0.332	0.170	0.155	0.159
31	0.179*		0.141	0.209		0.776		0.596		0.167	0.147	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	5.071	5.229	4.988	4.943	5.131	32.901	55.180	56.262	15.556	6.977	4.876	4.677
TOTAL FLOW (cms days)	0.144	0.148	0.141	0.140	0.145	0.932	1.563	1.593	0.441	0.198	0.138	0.132
TOTAL DEPTH (in)	0.447	0.461	0.440	0.436	0.452	2.900	4.864	4.960	1.371	0.615	0.430	0.412
TOTAL DEPTH (cm)	1.135	1.171	1.117	1.107	1.149	7.367	12.355	12.598	3.483	1.562	1.092	1.047

ANNUAL SUMMARY:
Sum of Mean Daily Flow 201.789 cfs = 5.715 cms
Total Depth 17.789 in = 45.183 cm
Maximum Instantaneous Flow 3.444 cfs = 0.098 cms on May 8 at 07.50 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 5
WATERSHED AREA: 270 ACRES (109 HECTARES)

WATER YEAR 1973
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.156	0.156	0.154	0.179	0.163	0.233	0.473	0.729	0.222	0.145	0.092	0.103
2	0.154	0.159	0.160	0.150	0.163	0.234	0.465	0.696	0.222	0.143	0.093	0.098
3	0.152	0.162	0.168	0.150	0.163	0.230	0.463	0.671	0.214	0.141	0.097	0.095
4	0.151	0.204	0.163	0.141	0.166	0.251	0.500	0.693	0.208	0.140	0.093	0.093
5	0.151	0.198	0.158	0.135	0.164	0.240	0.587	0.691	0.203	0.128	0.100	0.093
6	0.151	0.172	0.153	0.146	0.164	0.242	0.640	0.644	0.196	0.120	0.111	0.092
7	0.151	0.169	0.147	0.145	0.170	0.242	0.635	0.620	0.193	0.119	0.107	0.154
8	0.151	0.170	0.134	0.136	0.167	0.236	0.613	0.616	0.194	0.118	0.110	0.116
9	0.159	0.171	0.107	0.118	0.166	0.216	0.606	0.584	0.189	0.117	0.109	0.108
10	0.200	0.171	0.106	0.131	0.166	0.227	0.621	0.560	0.186	0.115	0.108	0.104
11	0.201	0.171	0.128	0.139	0.166	0.217	0.695	0.527	0.183	0.116	0.087	0.103
12	0.172	0.168	0.143	0.149	0.166	0.221	0.847	0.500	0.182	0.117	0.085	0.102
13	0.166	0.166	0.134	0.246	0.163	0.229	1.185	0.485	0.182	0.119	0.083	0.100
14	0.166	0.168	0.125	0.236	0.161	0.236	1.232	0.463	0.235	0.119	0.087	0.101
15	0.175	0.171	0.111	0.186	0.161	0.238	1.141	0.448	0.217	0.122	0.094	0.101
16	0.173	0.171	0.114	0.303	0.161	0.238	1.065	0.433	0.207	0.123	0.098	0.099
17	0.171	0.200	0.120	0.326	0.161	0.265	1.092	0.412	0.218	0.121	0.109	0.109
18	0.168	0.200	0.133	0.273	0.161	0.255	1.028	0.391	0.200	0.122	0.109	0.100
19	0.166	0.193	0.203	0.233	0.162	0.272	0.958	0.375	0.184	0.125	0.110	0.124
20	0.166	0.183	0.167	0.225	0.163	0.255	0.870	0.357	0.176	0.127	0.106	0.187
21	0.166	0.172	0.284	0.217	0.163	0.270	0.814	0.330	0.170	0.121	0.103	0.134
22	0.166	0.172	0.423	0.215	0.165	0.298	0.817	0.311	0.163	0.124	0.095	0.132
23	0.165	0.172	0.258	0.212	0.171	0.294	0.884	0.327	0.168	0.125	0.096	0.136
24	0.163	0.173	0.216	0.207	0.172	0.315	0.925	0.352	0.166	0.122	0.094	0.194
25	0.163	0.170	0.195	0.201	0.174	0.386	0.936	0.371	0.162	0.118	0.098	0.171
26	0.162	0.195	0.188	0.195	0.176	0.464	0.933	0.305	0.159	0.114	0.095	0.142
27	0.161	0.177	0.181	0.180	0.183	0.475	0.976	0.267	0.158	0.103	0.094	0.136
28	0.161	0.169	0.173	0.157	0.191	0.475	0.950	0.240	0.158	0.099	0.092	0.132
29	0.159	0.141	0.171	0.168		0.475	0.851	0.229	0.152	0.095	0.092	0.128
30	0.157	0.170	0.193	0.168		0.475	0.769	0.221	0.149	0.096	0.091	0.126
31	0.156		0.153	0.166		0.475		0.221		0.094	0.106	
MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	5.074	5.232	5.264	5.831	4.668	9.180	24.568	14.068	5.616	3.709	3.043	3.612
TOTAL FLOW (cms days)	0.144	0.148	0.149	0.165	0.132	0.260	0.696	0.398	0.159	0.105	0.086	0.102
TOTAL DEPTH (in)	0.447	0.461	0.464	0.514	0.412	0.809	2.166	1.240	0.495	0.327	0.268	0.318
TOTAL DEPTH (cm)	1.136	1.171	1.179	1.306	1.045	2.056	5.501	3.150	1.258	0.830	0.681	0.809

ANNUAL SUMMARY:
Sum of Mean Daily Flow 89.865 cfs = 2.545 cms
Total Depth 7.922 in = 20.122 cm
Maximum Instantaneous Flow 1.247 cfs = 0.035 cms on April 13 at 24.00 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 5
WATERSHED AREA: 270 ACRES (109 HECTARES)

WATER YEAR 1974
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.126	0.143	0.266	0.255*	0.504	0.480	3.547	4.222	0.704	0.305	0.204	0.152
2	0.125	0.113	0.271	0.255*	0.486	0.479	3.054	4.018	0.683	0.298	0.207	0.152
3	0.124	0.103	0.267	0.255*	0.475	0.447	2.705	3.819	0.655	0.291	0.210	0.153
4	0.124	0.098	0.262	0.255*	0.468	0.440	2.345	3.688	0.665	0.278	0.207	0.153
5	0.124	0.103	0.255	0.255*	0.447	0.458	2.231	3.715	0.686	0.269	0.202	0.153
6	0.124	0.190	0.250	0.255*	0.424	0.530	2.419	3.767	0.635	0.262	0.223	0.151
7	0.146	0.155	0.282	0.253*	0.416	0.501	2.389	3.788	0.607	0.257	0.229	0.145
8	0.141	0.147	0.295	0.265*	0.400	0.491	2.520	3.675	0.581	0.263	0.207	0.143
9	0.133	0.184	0.269	0.274*	0.389	0.483	2.819	3.462	0.561	0.325	0.190	0.144
10	0.129	0.424	0.265	0.269*	0.389	0.480	2.815	3.112	0.538	0.331	0.186	0.145
11	0.127	0.613	0.258	0.269*	0.387	0.482	2.859	2.656	0.526	0.337	0.185	0.145
12	0.126	1.139	0.258	0.267*	0.384	0.545	2.969	2.420	0.514	0.295	0.183	0.147
13	0.125	0.782	0.258	0.247*	0.378	0.597	2.912	2.158	0.491	0.281	0.182	0.148
14	0.123	0.539	0.258	0.259*	0.369	0.612	3.122	1.902	0.479	0.278	0.182	0.148
15	0.121	0.453	0.257	0.440*	0.358	0.638	3.455	1.719	0.460	0.280	0.179	0.149
16	0.119	0.448	0.268	1.092*	0.354	0.727	3.922	1.572	0.445	0.274	0.174	0.147
17	0.115	0.468	0.294*	1.902*	0.358	1.340	4.548	1.497	0.431	0.263	0.170	0.146
18	0.112	0.427	0.289*	1.823*	0.358	1.679	5.372	1.376	0.413	0.254	0.169	0.146
19	0.110	0.389	0.283*	1.383*	0.356	1.741	6.090	1.267	0.394	0.245	0.176	0.146
20	0.108	0.352	0.278*	1.149*	0.352	1.691	5.891	1.212	0.400	0.236	0.216	0.147
21	0.107	0.329	0.276*	1.008*	0.348	1.622	5.609	1.129	0.389	0.227	0.195	0.148
22	0.106	0.311	0.278*	0.911*	0.345	1.524	5.478	1.094	0.367	0.218	0.181	0.148
23	0.138	0.298	0.280*	0.787	0.339	1.402	6.146	1.072	0.353	0.213	0.174	0.148
24	0.130	0.281	0.278*	0.738	0.351	1.368	6.872	1.050	0.342	0.213	0.170	0.148
25	0.151	0.264	0.271*	0.697	0.333	1.427	6.896	1.029	0.327	0.207	0.167	0.150
26	0.116	0.255	0.265*	0.646	0.333	1.739	6.311	0.970	0.323	0.208	0.166	0.147
27	0.110	0.248	0.267*	0.612	0.329	2.180	5.427	0.911	0.323	0.211	0.162	0.146
28	0.107	0.242	0.271*	0.582	0.350	3.115	4.466	0.860	0.321	0.209	0.160	0.148
29	0.105	0.250	0.269*	0.559		3.042	3.961	0.819	0.321	0.201	0.158	0.147
30	0.104	0.258	0.262*	0.537		3.517	3.964	0.790	0.311	0.208	0.158	0.146
31	0.146		0.257*	0.517		3.764		0.723		0.204	0.156	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	3.801	10.006	8.354	19.017	10.778	39.542	123.113	65.492	14.245	7.938	5.728	4.437
TOTAL FLOW (cms days)	0.108	0.283	0.237	0.539	0.305	1.120	3.487	1.855	0.403	0.225	0.162	0.126
TOTAL DEPTH (in)	0.335	0.882	0.736	1.676	0.950	3.486	10.853	5.773	1.256	0.700	0.505	0.391
TOTAL DEPTH (cm)	0.851	2.241	1.871	4.258	2.413	8.854	27.566	14.664	3.190	1.777	1.283	0.994

ANNUAL SUMMARY:
Sum of Mean Daily Flow 312.453 cfs = 8.849 cms
Total Depth 27.544 in = 69.962 cm
Maximum Instantaneous Flow 7.182 cfs = 0.203 cms on April 24 at 17.00 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 5
WATERSHED AREA: 270 ACRES (109 HECTARES)

WATER YEAR 1975
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.146	0.168	0.177*	0.132	0.168*	0.162	0.183	0.793	0.926	0.262	0.157	0.158
2	0.145	0.168	0.176*	0.129	0.171*	0.191	0.185	1.027	0.844	0.252	0.152	0.158
3	0.142	0.167	0.177	0.130	0.176*	0.192	0.210	1.620	0.752	0.252	0.152	0.157
4	0.142	0.168	0.206	0.139	0.180	0.192	0.208	1.710	0.702	0.252	0.146	0.155
5	0.145	0.169	0.197	0.142	0.174	0.193	0.208	1.356	0.652	0.250	0.144	0.148
6	0.150	0.170	0.190	0.141	0.171	0.193	0.209	1.175	0.619	0.236	0.141	0.146
7	0.145	0.196	0.187	0.137	0.163	0.193	0.208	1.103	0.584	0.224	0.143	0.144
8	0.143	0.204	0.179	0.134	0.164	0.224	0.209	1.248	0.553	0.209	0.139	0.144
9	0.155	0.177	0.176	0.130	0.169	0.256	0.205	1.698	0.525	0.193	0.140	0.143
10	0.166	0.174	0.173	0.130	0.161	0.256	0.202	2.557	0.498	0.172	0.140	0.143
11	0.158	0.172	0.173	0.135	0.160	0.234	0.204	3.470	0.469	0.173	0.136	0.142
12	0.157	0.172	0.174	0.133	0.162	0.219	0.227	4.014	0.441	0.175	0.136	0.137
13	0.153	0.173	0.176	0.133	0.174	0.212	0.281	4.497	0.424	0.174	0.134	0.131
14	0.152	0.172	0.171	0.136	0.174	0.208	0.353	5.227	0.402	0.173	0.145	0.304
15	0.153	0.170	0.171	0.143	0.162	0.207	0.376	5.839	0.388	0.172	0.148	0.177
16	0.153	0.169	0.170	0.139	0.161	0.201	0.393	5.524	0.372	0.171	0.136	0.160
17	0.152	0.170	0.170	0.141	0.159	0.190	0.407	5.020	0.424	0.173	0.140	0.154
18	0.151	0.218	0.161	0.151	0.159	0.241	0.487	4.282	0.519	0.174	0.181	0.146
19	0.154	0.205	0.156	0.157	0.159	0.302	0.583	3.645	0.449	0.173	0.184	0.141
20	0.156	0.192	0.155	0.158	0.160	0.259	0.618	2.884	0.440	0.171	0.176	0.141
21	0.186	0.189	0.148*	0.159*	0.157	0.245	0.684	2.442	0.410	0.171	0.163	0.141
22	0.182	0.206	0.143*	0.160*	0.159	0.236	0.830	2.139	0.385	0.174	0.194	0.139
23	0.176	0.196	0.141*	0.167*	0.162	0.226	1.032	1.962	0.374	0.175	0.208	0.137
24	0.169	0.198	0.142*	0.169*	0.158	0.217	0.981	1.768	0.372	0.172	0.188	0.136
25	0.169	0.197	0.141*	0.250*	0.158	0.211	1.156	1.562	0.378	0.169	0.165	0.132
26	0.164	0.188	0.142*	0.224*	0.158	0.203	0.999	1.447	0.366	0.166	0.151	0.132
27	0.167	0.187	0.143*	0.191*	0.164	0.195	0.877	1.394	0.345	0.167	0.143	0.136
28	0.164	0.179*	0.143*	0.176*	0.163	0.212	0.809	1.277	0.331	0.162	0.173	0.134
29	0.165	0.171*	0.136	0.173		0.196	0.740	1.186	0.318	0.173	0.170	0.131
30	0.170	0.175*	0.136	0.163*		0.201	0.737	1.125	0.295	0.179	0.160	0.130
31	0.169		0.137	0.165*		0.197		1.023		0.160	0.158	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	4.902	5.461	5.068	4.767	4.605	6.665	14.801	76.014	14.557	5.899	4.845	4.478
TOTAL FLOW (cms days)	0.139	0.155	0.144	0.135	0.130	0.189	0.419	2.153	0.412	0.167	0.137	0.127
TOTAL DEPTH (in)	0.432	0.481	0.447	0.420	0.406	0.588	1.305	6.701	1.283	0.520	0.427	0.395
TOTAL DEPTH (cm)	1.098	1.223	1.135	1.067	1.031	1.492	3.314	17.020	3.259	1.321	1.085	1.003

ANNUAL SUMMARY:
Sum of Mean Daily Flow 152.060 cfs = 4.306 cms
Total Depth 13.405 in = 34.048 cm
Maximum Instantaneous Flow 6.029 cfs = 0.171 cms on May 15 at 19.00 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 5
WATERSHED AREA: 270 ACRES (109 HECTARES)

WATER YEAR 1976
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.126	0.173	0.331	0.211	0.205	0.230	0.655	3.255	0.589	0.237	0.197	0.146
2	0.135	0.173	0.416	0.205	0.199	0.226	0.719	3.971	0.563	0.231	0.193	0.144
3	0.131	0.173	0.363	0.203	0.201	0.228	0.799	4.275	0.539	0.225	0.184	0.145
4	0.130	0.173	0.350	0.202	0.206	0.229	1.129	4.311	0.515	0.220	0.179	0.143
5	0.130	0.173	0.431	0.203	0.209	0.231	1.624	3.967	0.491	0.220	0.176	0.141
6	0.192	0.180	0.369	0.198	0.212	0.234	1.730	3.582	0.473	0.222	0.173	0.155
7	0.269	0.224	0.517	0.195	0.218	0.238	1.792	3.436	0.460	0.225	0.170	0.152
8	0.177	0.194	0.580	0.190	0.218	0.239	1.951	3.282	0.448	0.223	0.175	0.144
9	0.161	0.176	0.543	0.188	0.216	0.236	2.413	3.109	0.430	0.220	0.176	0.143
10	0.154	0.175	0.485	0.187	0.210	0.231	2.751	2.888	0.427	0.219	0.164	0.143
11	0.214	0.165	0.437	0.186	0.210	0.228	2.964	2.708	0.460	0.216	0.161	0.181
12	0.211	0.159	0.402	0.184	0.210	0.227	3.090	2.275	0.419	0.221	0.161	0.174
13	0.180	0.166	0.364	0.181	0.210	0.227	3.101	1.990	0.415	0.215	0.157	0.158
14	0.171	0.163	0.318	0.184	0.212	0.231	3.002	1.775	0.391	0.210	0.156	0.155
15	0.163	0.210	0.302	0.191	0.212	0.235	2.915	1.551	0.377	0.208	0.216	0.154
16	0.159	0.254	0.293	0.209	0.222	0.243	2.528	1.375	0.397	0.204	0.209	0.164
17	0.153	0.217	0.271	0.206	0.234	0.248	2.250	1.235	0.393	0.222	0.187	0.175
18	0.147	0.191	0.262	0.194	0.232	0.259	2.115	1.128	0.364	0.383	0.179	0.174
19	0.144	0.176	0.272	0.193	0.232	0.270	2.019	1.032	0.353	0.263	0.178	0.174
20	0.142	0.158	0.269	0.197	0.230	0.263	2.073	0.947	0.354	0.236	0.173	0.165
21	0.190	0.159	0.256	0.209	0.224	0.259	2.105	0.897	0.380	0.222	0.167	0.156
22	0.189	0.158	0.252	0.204	0.221	0.261	2.135	0.843	0.366	0.208	0.165	0.155
23	0.166	0.159	0.248	0.201	0.224	0.301	2.185	0.801	0.350	0.192	0.187	0.155
24	0.156	0.159	0.241	0.198	0.226	0.335	2.459	0.769	0.339	0.206	0.181	0.155
25	0.158	0.159	0.237	0.200	0.227	0.369	3.172	0.739	0.332	0.201	0.170	0.155
26	0.215	0.160	0.233	0.205	0.232	0.380	2.859	0.705	0.315	0.189	0.174	0.154
27	0.185	0.157	0.231	0.208	0.240	0.394	2.687	0.670	0.297	0.184	0.165	0.149
28	0.173	0.144	0.223	0.210	0.234	0.415	2.542	0.658	0.263	0.183	0.157	0.148
29	0.171	0.197	0.221	0.211	0.232	0.441	2.561	0.627	0.242	0.179	0.156	0.147
30	0.169	0.355	0.216	0.210		0.457	2.747	0.603	0.234	0.187	0.150	0.146
31	0.172		0.214	0.209		0.500		0.639		0.187	0.148	
MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	5.234	5.481	10.147	6.174	6.358	8.866	67.073	60.045	11.977	6.758	5.381	4.649
TOTAL FLOW (cms days)	0.148	0.155	0.287	0.175	0.180	0.251	1.900	1.700	0.339	0.191	0.152	0.132
TOTAL DEPTH (in)	0.461	0.483	0.895	0.544	0.560	0.782	5.913	5.293	1.056	0.596	0.474	0.410
TOTAL DEPTH (cm)	1.172	1.227	2.272	1.382	1.424	1.985	15.018	13.445	2.682	1.513	1.205	1.041

ANNUAL SUMMARY:
Sum of Mean Daily Flow 198.142 cfs = 5.611 cms
Total Depth 17.467 in = 44.366 cm
Maximum Instantaneous Flow 4.427 cfs = 0.125 cms on May 3 at 18.00 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 5
WATERSHED AREA: 270 ACRES (109 HECTARES)

WATER YEAR 1977
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.141	0.162	0.145	0.100	0.141	0.140	0.159	0.149	0.161	0.125	0.093	0.096
2	0.145	0.169	0.135	0.100	0.140	0.139	0.158	0.147	0.157	0.128	0.094	0.091
3	0.145	0.170	0.125	0.105	0.141	0.139	0.156	0.163	0.150	0.133	0.095	0.089
4	0.144	0.167	0.128	0.109	0.141	0.142	0.152	0.174	0.145	0.137	0.091	0.088
5	0.143	0.164	0.130	0.103	0.141	0.144	0.153	0.163	0.143	0.128	0.091	0.089
6	0.143	0.167	0.127	0.104	0.141	0.142	0.169	0.164	0.139	0.123	0.090	0.085
7	0.144	0.163	0.126	0.105	0.141	0.142	0.195	0.175	0.238	0.121	0.091	0.084
8	0.144	0.158	0.128	0.107	0.140	0.144	0.238	0.176	0.205	0.119	0.119	0.084
9	0.142	0.158	0.129	0.109	0.139	0.146	0.239	0.161	0.166	0.120	0.096	0.081
10	0.143	0.157	0.131	0.113	0.138	0.147	0.225	0.181	0.242	0.120	0.091	0.089
11	0.141	0.158	0.133	0.112	0.141	0.147	0.215	0.172	0.233	0.116	0.087	0.113
12	0.141	0.158	0.127	0.113	0.139	0.148	0.214	0.160	0.203	0.113	0.086	0.115
13	0.142	0.156	0.126	0.114	0.139	0.147	0.218	0.149	0.185	0.111	0.084	0.107
14	0.141	0.156	0.126	0.115	0.140	0.146	0.216	0.136	0.183	0.107	0.083	0.105
15	0.141	0.157	0.129	0.117	0.139	0.147	0.214	0.132	0.178	0.106	0.084	0.115
16	0.140	0.155	0.129	0.121	0.140	0.148	0.213	0.146	0.164	0.105	0.082	0.148
17	0.136	0.157	0.127	0.125	0.134	0.147	0.210	0.148	0.154	0.103	0.080	0.164
18	0.136	0.156	0.120	0.126	0.138	0.148	0.205	0.146	0.147	0.101	0.080	0.130
19	0.131	0.158	0.105	0.128	0.138	0.146	0.204	0.143	0.145	0.102	0.080	0.127
20	0.132	0.157	0.090	0.130	0.139	0.146	0.199	0.134	0.156	0.104	0.079	0.146
21	0.152	0.161	0.085	0.131	0.139	0.146	0.197	0.126	0.154	0.108	0.083	0.142
22	0.158	0.167	0.094	0.135	0.139	0.146	0.193	0.126	0.144	0.116	0.081	0.133
23	0.158	0.168	0.100	0.140	0.138	0.146	0.189	0.190	0.140	0.126	0.078	0.128
24	0.158	0.180	0.100	0.141	0.137	0.147	0.181	0.183	0.132	0.176	0.096	0.208
25	0.170	0.180	0.101	0.144	0.135	0.148	0.174	0.186	0.127	0.141	0.112	0.143
26	0.169	0.177	0.102	0.142	0.138	0.149	0.173	0.185	0.127	0.125	0.145	0.133
27	0.163	0.175	0.103	0.141	0.139	0.147	0.171	0.207	0.125	0.119	0.112	0.116
28	0.162	0.170	0.102	0.141	0.138	0.147	0.170	0.192	0.124	0.110	0.106	0.106
29	0.160	0.161	0.104	0.141		0.147	0.162	0.185	0.120	0.102	0.101	0.154
30	0.162	0.156	0.103	0.141		0.148	0.158	0.174	0.123	0.107	0.097	0.122
31	0.162		0.101	0.141		0.157		0.168		0.093	0.097	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	4.589	4.897	3.608	3.797	3.893	4.524	5.722	5.041	4.809	3.647	2.882	3.531
TOTAL FLOW (cms days)	0.130	0.139	0.102	0.108	0.110	0.128	0.162	0.143	0.136	0.103	0.082	0.100
TOTAL DEPTH (in)	0.405	0.432	0.318	0.335	0.343	0.399	0.504	0.444	0.424	0.321	0.254	0.311
TOTAL DEPTH (cm)	1.027	1.097	0.808	0.850	0.872	1.013	1.281	1.129	1.077	0.817	0.645	0.791

ANNUAL SUMMARY:

Sum of Mean Daily Flow	50.938 cfs =	1.443 cms
Total Depth	4.490 in =	11.406 cm
Maximum Instantaneous Flow	1.134 cfs =	0.032 cms on June 7 at 21.00 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 5
WATERSHED AREA: 270 ACRES (109 HECTARES)

WATER YEAR 1978
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.106	0.108	0.116	0.167	0.168	0.251	4.259	1.389	0.534	0.219	0.117	0.095
2	0.103	0.108	0.155	0.167	0.168	0.255	3.612	1.330	0.521	0.243	0.111	0.088
3	0.099	0.105	0.225	0.166	0.168	0.252	2.982	1.293	0.508	0.253	0.116	0.082
4	0.098	0.102	0.193	0.163	0.168	0.252	2.544	1.240	0.483	0.242	0.120	0.087
5	0.096	0.117	0.162	0.163	0.169	0.257	2.197	1.203	0.467	0.209	0.117	0.094
6	0.094	0.117	0.151	0.163	0.167	0.282	2.002	1.171	0.441	0.180	0.119	0.151
7	0.097	0.110	0.144	0.162	0.169	0.296	1.911	1.162	0.423	0.181	0.120	0.142
8	0.097	0.101	0.130	0.162	0.170	0.344	1.827	1.161	0.399	0.193	0.115	0.125
9	0.098	0.100	0.121	0.161	0.170	0.510	1.834	1.140	0.379	0.201	0.110	0.083
10	0.098	0.100	0.121	0.158	0.168	0.588	1.992	1.114	0.357	0.211	0.111	0.101
11	0.097	0.100	0.116	0.159	0.169	0.608	2.171	1.076	0.343	0.194	0.115	0.092
12	0.096	0.099	0.117	0.158	0.170	0.608	2.157	1.044	0.335	0.190	0.117	0.093
13	0.094	0.100	0.123	0.169	0.170	0.595	2.129	1.006	0.323	0.176	0.179	0.097
14	0.093	0.100	0.527	0.168	0.170	0.576	2.121	0.966	0.308	0.170	0.137	0.110
15	0.092	0.171	1.628	0.169	0.169	0.542	2.067	0.937	0.298	0.174	0.113	0.096
16	0.093	0.143	0.761	0.168	0.169	0.518	2.025	0.896	0.283	0.175	0.129	0.095
17	0.092	0.118	0.496	0.168	0.168	0.528	1.986	0.861	0.271	0.181	0.128	0.098
18	0.092	0.101	0.380	0.168	0.168	0.681	1.915	0.834	0.259	0.188	0.215	0.103
19	0.090	0.105	0.299	0.168	0.169	0.886	1.866	0.827	0.245	0.177	0.130	0.111
20	0.091	0.075	0.286	0.169	0.168	1.082	1.805	0.805	0.230	0.156	0.137	0.118
21	0.090	0.072	0.247	0.169	0.174	1.303	1.742	0.801	0.240	0.147	0.142	0.110
22	0.090	0.081	0.230	0.169	0.185	1.641	1.686	0.777	0.248	0.145	0.152	0.107
23	0.089	0.091	0.216	0.168	0.195	2.179	1.644	0.749	0.242	0.129	0.128	0.106
24	0.089	0.093	0.197	0.171	0.203	2.413	1.601	0.722	0.253	0.123	0.097	0.109
25	0.092	0.131	0.174	0.168	0.214	2.110	1.594	0.691	0.292	0.125	0.093	0.115
26	0.105	0.255	0.167	0.169	0.226	2.326	1.595	0.661	0.254	0.130	0.088	0.120
27	0.100	0.156	0.164	0.170	0.232	2.855	1.570	0.626	0.238	0.134	0.088	0.112
28	0.100	0.134	0.163	0.169	0.244	3.248	1.523	0.598	0.227	0.141	0.087	0.103
29	0.100	0.127	0.161	0.168		3.698	1.486	0.576	0.206	0.140	0.096	0.100
30	0.119	0.123	0.161	0.168		4.306	1.430	0.547	0.234	0.136	0.107	0.101
31	0.111		0.159	0.168		4.150		0.536		0.128	0.101	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	3.000	3.441	8.290	5.153	5.049	40.140	61.273	28.740	9.842	5.390	3.735	3.143
TOTAL FLOW (cms days)	0.085	0.097	0.235	0.146	0.143	1.137	1.735	0.814	0.279	0.153	0.106	0.089
TOTAL DEPTH (in)	0.264	0.303	0.731	0.454	0.445	3.538	5.401	2.534	0.868	0.475	0.329	0.277
TOTAL DEPTH (cm)	0.672	0.770	1.856	1.154	1.130	8.988	13.720	6.435	2.204	1.207	0.836	0.704

ANNUAL SUMMARY:
Sum of Mean Daily Flow 177.194 cfs = 5.018 cms
Total Depth 15.620 in = 39.676 cm
Maximum Instantaneous Flow 4.494 cfs = 0.127 cms on March 30 at 04.00 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 5
WATERSHED AREA: 270 ACRES (109 HECTARES)

WATER YEAR 1979
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.116	0.104	0.119	0.158	0.161	0.121	0.218	0.729	0.230	0.117*	0.078	0.082
2	0.120	0.103	0.114	0.163	0.161	0.118	0.220	0.684	0.223	0.116*	0.076	0.075
3	0.128	0.104	0.112	0.165	0.161	0.117	0.224	0.612	0.218	0.114*	0.074	0.074
4	0.125	0.104	0.208	0.166	0.163	0.117	0.228	0.569	0.211	0.112*	0.073	0.074
5	0.119	0.103	0.145	0.166	0.164	0.116	0.233	0.564	0.204	0.110*	0.071	0.073
6	0.113	0.103	0.123	0.165	0.164	0.117*	0.252	0.577	0.195	0.108*	0.071	0.074
7	0.112	0.103	0.124*	0.165	0.162	0.121*	0.444	0.541	0.191	0.106*	0.069	0.073
8	0.113	0.111	0.124*	0.167	0.160	0.131*	0.433	0.527	0.187	0.104*	0.077	0.068
9	0.115	0.117	0.124*	0.169	0.159	0.162*	0.588	0.509	0.179	0.103*	0.075	0.064
10	0.122	0.107	0.124*	0.170	0.157	0.218*	0.531	0.481	0.170	0.100*	0.071	0.064
11	0.129	0.105*	0.124*	0.171	0.156	0.236*	0.435	0.497	0.161	0.093	0.070	0.065
12	0.125	0.106*	0.125*	0.172	0.156	0.255*	0.400	0.498	0.151	0.102	0.085	0.065
13	0.118	0.105*	0.126*	0.172	0.157	0.247*	0.397	0.471	0.146	0.098	0.121	0.065
14	0.119	0.104*	0.126*	0.170	0.153	0.236*	0.419	0.452	0.141	0.096	0.091	0.064
15	0.118	0.102*	0.127*	0.168	0.151	0.227*	0.500	0.429	0.135	0.095	0.076	0.061
16	0.118	0.101	0.127*	0.167	0.151	0.227*	0.625	0.415	0.130	0.093	0.068	0.060
17	0.117	0.101	0.127*	0.166	0.151	0.228*	0.902	0.391	0.133	0.091	0.093	0.061
18	0.115	0.100	0.127*	0.165	0.151	0.228*	0.803	0.372	0.141	0.088	0.101	0.063
19	0.113	0.102	0.127*	0.165	0.150	0.228*	0.653	0.353	0.143	0.085	0.093	0.062
20	0.114	0.105	0.130	0.165	0.145	0.228*	0.577	0.336	0.138	0.088	0.082	0.062
21	0.114	0.106	0.138	0.165	0.142	0.224*	0.572	0.326	0.123	0.090	0.080	0.061
22	0.112	0.109	0.142	0.165	0.141	0.216	0.627	0.317	0.134*	0.098	0.079	0.060
23	0.112	0.108	0.141	0.164	0.139	0.212	0.733	0.307	0.135*	0.091	0.096	0.059
24	0.113	0.102	0.138	0.164	0.137	0.209	0.735	0.299	0.132*	0.086	0.098	0.060*
25	0.113	0.105	0.134	0.165	0.135	0.206	0.705	0.291	0.130*	0.085	0.081	0.084*
26	0.112	0.108	0.136	0.165	0.131	0.203	0.712	0.276	0.128*	0.083	0.078	0.094
27	0.110	0.111	0.141	0.164	0.127	0.197	0.742*	0.268	0.126*	0.083	0.088	0.073
28	0.107	0.105	0.147	0.164	0.124	0.244	0.773	0.261	0.124*	0.083	0.087	0.069
29	0.107	0.104	0.148	0.163		0.350	0.766	0.252	0.122*	0.082	0.080	0.068
30	0.107	0.114	0.151	0.161		0.234	0.752	0.245	0.120*	0.080	0.083	0.067
31	0.105		0.155	0.160		0.217		0.236		0.079	0.090	
MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	3.580	3.164	4.156	5.134	4.207	6.189	16.197	13.086	4.700	2.961	2.555	2.046
TOTAL FLOW (cms days)	0.101	0.090	0.118	0.145	0.119	0.175	0.459	0.371	0.133	0.084	0.072	0.058
TOTAL DEPTH (in)	0.316	0.279	0.366	0.453	0.371	0.546	1.428	1.154	0.414	0.261	0.225	0.180
TOTAL DEPTH (cm)	0.802	0.708	0.931	1.150	0.942	1.386	3.627	2.930	1.052	0.663	0.572	0.458

ANNUAL SUMMARY:
Sum of Mean Daily Flow 67.974 cfs = 1.925 cms
Total Depth 5.992 in = 15.220 cm
Maximum Instantaneous Flow 0.947 cfs = 0.027 cms on April 17 at 05.07 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 5
WATERSHED AREA: 270 ACRES (109 HECTARES)

WATER YEAR 1980
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.066	0.115	0.122*	0.138	0.166	0.377*	0.373	1.577	0.678	0.249	0.129	0.123
2	0.066	0.114	0.139*	0.137	0.166	0.411*	0.373	1.415	0.677	0.272	0.128	0.149
3	0.067	0.113	0.173*	0.136	0.166	0.422*	0.363	1.273	0.644*	0.256	0.126	0.118
4	0.067	0.114	0.163*	0.136	0.164	0.433*	0.368	1.146	0.614*	0.234	0.119	0.104
5	0.063	0.114	0.158*	0.137*	0.165	0.436*	0.404	1.042	0.680*	0.226	0.114	0.099
6	0.060	0.113	0.156*	0.139	0.165	0.425	0.453	0.947	0.619*	0.222	0.114	0.099
7	0.059	0.113	0.157*	0.139*	0.163	0.410	0.453	0.849	0.563*	0.214	0.113	0.099
8	0.059	0.112	0.159*	0.140*	0.160	0.396	0.455	0.801	0.515*	0.209	0.113	0.101
9	0.058	0.110	0.155*	0.139*	0.160	0.377	0.492	0.833	0.468*	0.210	0.112	0.109
10	0.058	0.106	0.186*	0.138	0.161	0.364	0.538	0.813	0.455*	0.202	0.110	0.134
11	0.058	0.105	0.168*	0.137	0.161	0.362	0.547	0.779	0.450*	0.196	0.110	0.169
12	0.058	0.102	0.169	0.186	0.163	0.355	0.632	0.694	0.494*	0.189	0.108	0.131
13	0.057	0.100	0.169	0.297	0.165	0.347	0.938	0.642	0.462*	0.189	0.107	0.167
14	0.056	0.096	0.168	0.474	0.165	0.380	1.419	0.576	0.502*	0.194	0.104	0.142
15	0.125*	0.093	0.165	0.447	0.165	0.418	1.886	0.577	0.514*	0.196	0.136	0.131
16	0.098	0.094	0.153	0.326	0.165	0.401	2.138	0.643	0.487*	0.188	0.129	0.126
17	0.099	0.095	0.149	0.278	0.169*	0.398	2.529	0.602	0.453	0.184	0.116	0.134
18	0.130	0.097	0.148	0.239	0.235*	0.386	3.323	0.581	0.426	0.179	0.118	0.164
19	0.229	0.098	0.145	0.212	0.417*	0.369	3.800	0.550	0.414	0.174	0.120	0.154
20	0.136	0.103*	0.146	0.203	0.435*	0.360	4.275	0.531	0.405	0.171	0.117	0.160
21	0.126	0.116*	0.146	0.195	0.426*	0.348	4.311	0.531	0.385	0.165	0.112	0.161
22	0.129	0.121*	0.143	0.190	0.405*	0.345	4.112	0.524	0.361	0.155	0.112	0.150
23	0.148	0.118*	0.137	0.182	0.379*	0.345	3.978	0.577	0.353	0.147	0.112	0.145
24	0.130	0.117*	0.136*	0.174	0.339*	0.348	3.753	0.570	0.338	0.140	0.111	0.149
25	0.147	0.116*	0.136*	0.168	0.298*	0.356	3.315	0.652	0.321	0.141	0.112	0.148
26	0.155	0.116*	0.137*	0.167	0.223*	0.367	2.856	0.754	0.307	0.131	0.114	0.150
27	0.133	0.116*	0.137*	0.167	0.161*	0.375	2.701	0.787	0.297	0.128	0.121	0.150
28	0.129	0.116*	0.137*	0.167	0.233*	0.376	2.546	0.778	0.281	0.124	0.125	0.151
29	0.122	0.115*	0.138*	0.168	0.309*	0.376	2.301	0.744	0.261	0.131	0.125	0.151
30	0.117	0.117*	0.138*	0.168		0.375	1.869	0.713	0.252	0.129	0.124	0.154
31	0.117		0.138*	0.167		0.373		0.676		0.131	0.124	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	3.121	3.275	4.670	6.089	6.650	11.811	57.500	24.179	13.677	5.675	3.634	4.122
TOTAL FLOW (cms days)	0.088	0.093	0.132	0.172	0.188	0.334	1.628	0.685	0.387	0.161	0.103	0.117
TOTAL DEPTH (in)	0.275	0.289	0.412	0.537	0.586	1.041	5.069	2.131	1.206	0.500	0.320	0.363
TOTAL DEPTH (cm)	0.699	0.733	1.046	1.363	1.489	2.645	12.875	5.414	3.063	1.271	0.814	0.923

ANNUAL SUMMARY:
Sum of Mean Daily Flow 144.402 cfs = 4.089 cms
Total Depth 12.730 in = 32.333 cm
Maximum Instantaneous Flow 4.725 cfs = 0.134 cms on April 20 at 19.97 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 6
WATERSHED AREA: 400 ACRES (161 HECTARES)

WATER YEAR 1968
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.148	0.145	0.100*	0.147*	0.086*	0.767*	1.161	0.590	0.277	0.169	0.065	0.086
2	0.189	0.137	0.098*	0.145*	0.084*	0.706*	1.308	0.566	0.268	0.164	0.068	0.089
3	0.246	0.118	0.097*	0.143*	0.082*	0.817*	1.343	0.533	0.271	0.158	0.070	0.085
4	0.137	0.105	0.101*	0.140*	0.080*	1.021*	1.323	0.512	0.264	0.149	0.069	0.089
5	0.137	0.105	0.107*	0.137*	0.079*	1.139*	1.454	0.499	0.264	0.146	0.067	0.094*
6	0.133	0.101	0.108*	0.135*	0.082*	1.153*	1.423	0.478	0.279	0.142	0.066	0.086*
7	0.110	0.097	0.106*	0.133*	0.091*	1.061*	1.317	0.445	0.272	0.136	0.065	0.085*
8	0.105	0.097	0.105*	0.130*	0.096*	0.976*	1.195	0.418	0.259	0.130	0.062	0.083*
9	0.105	0.120	0.102*	0.127*	0.101*	0.899*	1.125	0.411*	0.261	0.133	0.062	0.082*
10	0.105	0.143	0.100*	0.125*	0.111*	0.863*	1.129	0.410*	0.260	0.130	0.107	0.080*
11	0.105	0.157	0.098*	0.124*	0.123*	0.829*	1.267	0.402*	0.240	0.113	0.076	0.079*
12	0.105	0.142	0.097*	0.122*	0.131*	0.762*	1.277	0.395*	0.233	0.123	0.071	0.078*
13	0.105	0.132	0.095*	0.120*	0.133*	0.701*	1.231	0.404	0.231	0.117	0.091	0.076*
14	0.110	0.119	0.094*	0.117*	0.131*	0.655*	1.086	0.380	0.226	0.112	0.211	0.075*
15	0.110	0.114*	0.092*	0.115*	0.128*	0.621*	0.994	0.359	0.244	0.109	0.199	0.074*
16	0.105	0.115*	0.091*	0.113*	0.125*	0.590*	0.917	0.345	0.223	0.107	0.119	0.072*
17	0.105	0.113*	0.089*	0.111*	0.124*	0.562*	0.853	0.333	0.210	0.104	0.122	0.071*
18	0.105	0.118*	0.088*	0.109*	0.142*	0.536*	0.803	0.324	0.203	0.100	0.150	0.070*
19	0.101	0.124*	0.085*	0.106*	0.428*	0.508*	0.749	0.318	0.196	0.091	0.148	0.068*
20	0.097	0.122*	0.085*	0.105*	1.201*	0.482*	0.706	0.361	0.203	0.090	0.180	0.069*
21	0.105	0.120*	0.084*	0.103*	1.615*	0.460*	0.666	0.327	0.192	0.089	0.185	0.089*
22	0.144	0.117*	0.080*	0.101*	1.490*	0.436*	0.633	0.313	0.196	0.085	0.169	0.108*
23	0.142	0.115*	0.079*	0.100*	1.374*	0.413*	0.606	0.312	0.214	0.080	0.141	0.106*
24	0.142	0.113*	0.078*	0.098*	1.268*	0.523*	0.586	0.302	0.188	0.079	0.124	0.104*
25	0.123	0.111*	0.093*	0.097*	1.167*	0.670*	0.572	0.363	0.183	0.078	0.111	0.101*
26	0.105	0.110*	0.135*	0.095*	1.074*	0.655*	0.565	0.350	0.176	0.076	0.107	0.100*
27	0.136	0.108*	0.161*	0.094*	0.989*	0.611*	0.553	0.325	0.169	0.076	0.106	0.098*
28	0.285	0.105*	0.159*	0.092*	0.908*	0.633*	0.553	0.307	0.170	0.073	0.102	0.097*
29	0.175	0.102*	0.157*	0.091*	0.834*	0.887	0.564	0.299	0.174	0.072	0.099	0.095*
30	0.161	0.101*	0.154*	0.089*		1.080	0.583	0.291	0.178	0.060	0.090	0.094*
31	0.152		0.150*	0.088*		1.114		0.284		0.068	0.086	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	4.135	3.527	3.266	3.549	14.275	23.130	28.543	11.956	6.723	3.359	3.390	2.582
TOTAL FLOW (cms days)	0.117	0.100	0.092	0.101	0.404	0.655	0.808	0.339	0.190	0.095	0.096	0.073
TOTAL DEPTH (in)	0.246	0.210	0.194	0.211	0.849	1.376	1.698	0.711	0.400	0.200	0.202	0.154
TOTAL DEPTH (cm)	0.625	0.533	0.494	0.536	2.158	3.496	4.314	1.807	1.016	0.508	0.512	0.390

ANNUAL SUMMARY:
Sum of Mean Daily Flow 108.437 cfs = 3.071 cms
Total Depth 6.452 in = 16.389 cm
Maximum Instantaneous Flow 1.680 cfs = 0.048 cms on February 20 at 24.00 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 6
WATERSHED AREA: 400 ACRES (161 HECTARES)

WATER YEAR 1969
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.089	0.105	0.164	0.122*	0.332*	0.192*	2.688	1.905	0.356	0.242*	0.113	0.088
2	0.095	0.104	0.162	0.121*	0.324*	0.190*	3.056	1.744	0.344	0.220	0.112	0.088
3	0.095	0.127	0.160	0.119*	0.315*	0.192	3.325	1.642	0.326	0.209	0.110	0.088
4	0.096	0.122	0.161	0.117*	0.305*	0.193	3.198	1.622	0.308	0.205	0.106	0.093
5	0.096	0.110	0.164	0.115*	0.296*	0.200	3.754	1.683	0.299	0.204	0.109	0.095
6	0.095	0.109	0.155	0.114*	0.287*	0.207	4.716	1.725	0.290	0.210	0.108	0.093
7	0.097	0.113	0.156	0.112*	0.279*	0.209	4.225	1.738	0.276	0.206	0.105	0.091
8	0.099	0.115	0.158	0.110*	0.275*	0.216	3.564	1.631	0.296	0.192	0.103	0.085
9	0.103	0.205	0.152	0.107*	0.271*	0.219	3.476	1.503	0.318	0.187	0.099	0.087
10	0.108	0.153	0.162	0.105*	0.265*	0.219	3.764	1.369	0.293	0.180	0.100	0.091
11	0.136	0.191	0.200	0.104*	0.227	0.222*	3.834	1.230	0.270	0.175	0.114	0.096
12	0.173	0.371	0.172	0.101*	0.214	0.229	3.916	1.093	0.264	0.172	0.108	0.099
13	0.165	0.251	0.183*	0.099*	0.217	0.234	4.121	0.997	0.248	0.169	0.106	0.097
14	0.145	0.195	0.166*	0.098*	0.208*	0.232	3.976	1.033	0.241	0.166	0.102	0.095
15	0.140	0.179	0.125*	0.095*	0.207	0.274*	3.664	0.888	0.238	0.154	0.100	0.103
16	0.141	0.165	0.162*	0.093*	0.206	0.295	3.512	0.784	0.229	0.150	0.100	0.102
17	0.132	0.156	0.159*	0.092*	0.205*	0.310*	3.553	0.722	0.220	0.146	0.099	0.099
18	0.130	0.174	0.157*	0.090*	0.205*	0.343	4.125	0.691	0.213	0.142	0.098	0.099
19	0.130	0.175*	0.153*	0.089*	0.205	0.339	3.844	0.673	0.232	0.140	0.097	0.135
20	0.143	0.170	0.150*	0.087*	0.202	0.339	3.428	0.664	0.254	0.137	0.095	0.178
21	0.141	0.170	0.148*	0.263*	0.200	0.353	3.350	0.608	0.239	0.134	0.094	0.132
22	0.133	0.233	0.146*	0.500*	0.200	0.440	3.891	0.559	0.229	0.131	0.090	0.121
23	0.132	0.238	0.144*	0.475*	0.200	0.483	4.460	1.009	0.267	0.130	0.087	0.128
24	0.130	0.217	0.141*	0.451*	0.200	0.487	4.505	0.492*	0.388	0.130	0.084	0.129
25	0.126	0.202	0.139*	0.428*	0.196	0.544	3.580	0.481	0.300	0.130	0.086	0.120
26	0.124	0.188	0.136*	0.407*	0.195	0.704	2.985	0.452	0.278	0.127	0.088	0.117
27	0.122	0.185	0.133*	0.521*	0.195	0.870	2.591	0.434	0.266*	0.124	0.089	0.114
28	0.123	0.174	0.131*	0.506*	0.194	0.973	2.370	0.415	0.264*	0.122	0.090	0.111
29	0.123	0.173	0.129*	0.368*		1.226	2.290	0.395	0.257*	0.119	0.095	0.113
30	0.131*	0.175	0.128*	0.356*		1.755	2.126	0.388	0.250*	0.116	0.096	0.120
31	0.113		0.125*	0.342*		2.390		0.374		0.114	0.090	

MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	3.806	5.244	4.720	6.706	6.623	15.077	105.885	30.946	8.250	4.982	3.073	3.208
TOTAL FLOW (cms days)	0.108	0.149	0.134	0.190	0.188	0.427	2.999	0.876	0.234	0.141	0.087	0.091
TOTAL DEPTH (in)	0.226	0.312	0.281	0.399	0.394	0.897	6.301	1.841	0.491	0.296	0.183	0.191
TOTAL DEPTH (cm)	0.575	0.793	0.713	1.014	1.001	2.279	16.004	4.677	1.247	0.753	0.464	0.485

ANNUAL SUMMARY:
Sum of Mean Daily Flow 198.521 cfs = 5.622 cms
Total Depth 11.813 in = 30.005 cm
Maximum Instantaneous Flow 4.991 cfs = 0.141 cms on April 24 at 02.25 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 6
WATERSHED AREA: 400 ACRES (161 HECTARES)

WATER YEAR 1970
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.118	0.121	0.093*	0.200*	0.570*	0.659	0.912	1.216	0.746	0.362*	0.153	0.102
2	0.152	0.121	0.092*	0.196*	0.540*	0.696	0.901	1.625	0.700	0.353	0.150	0.100
3	0.129	0.121	0.089*	0.194*	0.512*	0.671	0.885	2.303	0.656	0.331	0.149	0.100
4	0.121	0.121	0.087*	0.190*	0.485*	0.646	0.897	3.274	0.605	0.320	0.146	0.146
5	0.116	0.137	0.086*	0.187*	0.461*	0.613	1.070	4.501	0.562	0.306	0.159	0.142
6	0.114	0.170	0.084*	0.184*	0.437*	0.579	1.532	5.145	0.542	0.295	0.147	0.135
7	0.113	0.145	0.083*	0.180*	0.416*	0.566	1.959	5.028	0.528	0.284	0.141	0.136
8	0.148	0.133	0.082*	0.178*	0.396*	0.590	1.981	4.343	0.510	0.270	0.139	0.199
9	0.139	0.127	0.080*	0.175*	0.374*	0.581	2.033	4.287	0.551	0.262	0.137	0.132
10	0.127	0.125	0.079*	0.171*	0.359*	0.576	2.730	3.926	0.502	0.285	0.134	0.127
11	0.121	0.123	0.078*	0.169*	0.349*	0.580	2.949	3.337	0.452	0.265	0.129	0.124
12	0.119	0.121	0.077*	0.167*	0.349*	0.586	2.646	2.875	0.441	0.246	0.121	0.124
13	0.119	0.121	0.075*	0.164*	0.409	0.588	2.382	2.518	0.452	0.238	0.117	0.125
14	0.118	0.121	0.073*	0.161*	0.441	0.637	2.126	2.259	0.514	0.230	0.116	0.127
15	0.119	0.121	0.072*	0.158*	0.433	0.750*	1.897	2.180	0.509	0.223	0.112	0.128
16	0.120	0.121*	0.070*	0.155*	0.429	0.789	1.711	2.474	0.485	0.220	0.109	0.126
17	0.122	0.118*	0.069*	0.153*	0.585	0.797	1.590	2.903	0.447	0.224	0.108	0.123
18	0.122	0.116*	0.068*	0.150*	0.545	0.801	1.537	3.023	0.404	0.209	0.108	0.120
19	0.120	0.115*	0.067*	0.147*	0.516	0.776	1.533	2.778	0.381	0.201	0.106	0.181
20	0.119	0.112*	0.066*	0.163*	0.491*	0.746	1.462	2.423	0.362	0.196	0.103	0.166
21	0.118	0.110*	0.141*	0.218*	0.473	0.741	1.388	2.114	0.341	0.193	0.102	0.148
22	0.117	0.108*	0.237*	0.295*	0.475	0.745	1.320	1.875	0.328	0.190	0.100	0.136
23	0.117	0.107*	0.233*	0.440*	0.479	0.775	1.266	1.772	0.314	0.185	0.099	0.141
24	0.116	0.105*	0.229*	0.764*	0.485	0.851	1.227	1.545	0.301	0.181	0.101	0.131
25	0.116	0.103*	0.225*	0.956*	0.507	0.914	1.177	1.378	0.287	0.176	0.101	0.130
26	0.116	0.101*	0.221*	0.878*	0.539	0.952	1.143	1.248	0.282	0.174	0.100	0.131
27	0.128	0.099*	0.216*	0.805*	0.568	0.978	1.108	1.167	0.386	0.171	0.100	0.131
28	0.148	0.097*	0.213*	0.736*	0.595	1.016	1.091	1.034	0.370	0.176	0.100	0.128
29	0.129	0.096*	0.210*	0.676*		0.986	1.072	0.951	0.496	0.165	0.101	0.128
30	0.126	0.094*	0.207*	0.631*		0.953	1.091	0.873	0.439	0.161	0.103	0.126
31	0.124		0.203*	0.600*		0.927		0.803		0.158	0.104	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	3.829	3.529	3.904	10.442	13.216	23.065	46.616	77.177	13.893	7.247	3.694	3.994
TOTAL FLOW (cms days)	0.108	0.100	0.111	0.296	0.374	0.653	1.320	2.186	0.393	0.205	0.105	0.113
TOTAL DEPTH (in)	0.228	0.210	0.232	0.621	0.786	1.372	2.774	4.592	0.827	0.431	0.220	0.238
TOTAL DEPTH (cm)	0.579	0.533	0.590	1.578	1.998	3.486	7.046	11.665	2.100	1.095	0.558	0.604

ANNUAL SUMMARY:
Sum of Mean Daily Flow 210.608 cfs = 5.964 cms
Total Depth 12.532 in = 31.831 cm
Maximum Instantaneous Flow 5.376 cfs = 0.152 cms on May 6 at 23.00 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 6
WATERSHED AREA: 400 ACRES (161 HECTARES)

WATER YEAR 1971
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.120	0.147*	0.601*	0.370*	0.322*	0.335*	1.125*	6.041*	0.912*	0.494	0.228	0.151
2	0.119	0.154*	0.568*	0.375*	0.399*	0.325*	1.183*	7.005*	0.834*	0.481	0.235	0.166
3	0.119	0.161*	0.539*	0.388*	0.492*	0.325*	1.277*	8.093*	0.763*	0.451	0.223	0.156
4	0.118	0.158*	0.513*	0.419*	0.496*	0.325*	1.422*	8.504*	0.698*	0.418	0.209	0.157
5	0.118	0.189*	0.486*	0.449*	0.484*	0.316*	1.676*	8.636*	0.640*	0.396	0.204	0.153
6	0.123	0.248*	0.459*	0.465*	0.459*	0.306*	2.098*	8.479*	0.596*	0.379	0.206	0.159
7	0.125	0.275*	0.417*	0.482*	0.436*	0.296*	3.051*	7.791*	0.566*	0.363	0.200	0.180
8	0.125	0.265*	0.406*	0.490*	0.413*	0.285*	4.109*	7.152*	0.537*	0.348	0.196	0.154
9	0.138	0.293*	0.413*	0.478*	0.391*	0.277*	4.443*	6.569*	0.509*	0.331	0.190	0.150
10	0.153	0.331*	0.391*	0.451*	0.427*	0.268*	4.273*	6.040*	0.494*	0.322	0.186	0.146
11	0.136	0.322*	0.370*	0.428*	0.463*	0.328*	3.921*	5.548*	0.492*	0.316	0.183	0.144
12	0.131	0.311*	0.355*	0.406*	0.440*	0.382*	3.611*	5.093*	0.490*	0.316	0.180	0.144
13	0.130	0.300*	0.408*	0.386*	0.417*	0.388*	3.317*	4.680*	0.488*	0.305	0.177	0.143
14	0.132	0.291*	0.496*	0.404*	0.395*	0.400*	3.434*	4.298*	0.479	0.306	0.183	0.142
15	0.131	0.282*	0.507*	0.422*	0.421*	0.380*	4.212*	3.945*	0.482	0.300	0.174	0.144
16	0.130	0.274*	0.480*	0.402*	0.467*	0.360*	4.990*	3.626*	0.470	0.293	0.171	0.145
17	0.130	0.265*	0.455*	0.380*	0.477*	0.341*	5.489*	3.332*	0.456	0.287	0.170	0.145
18	0.132	0.258*	0.432*	0.393*	0.482*	0.351*	5.698*	3.060*	0.464	0.282	0.165	0.147
19	0.143	0.254*	0.409*	0.406*	0.484*	0.372*	5.831*	2.809*	0.462	0.306	0.163	0.148
20	0.156	0.250*	0.388*	0.404*	0.484*	0.363*	6.461*	2.578*	0.435	0.307	0.160	0.147
21	0.155	0.246*	0.368*	0.417*	0.484*	0.374*	7.439*	2.366*	0.414	0.290	0.159	0.145
22	0.176	0.242*	0.350*	0.436*	0.471*	0.384*	7.655*	2.170*	0.404	0.285	0.158	0.144
23	0.164	0.264*	0.340*	0.471*	0.448*	0.388*	7.035*	1.990*	0.387	0.281	0.158	0.145
24	0.178	0.617*	0.343*	0.480*	0.424*	0.446*	6.459*	1.825*	0.375	0.273	0.158	0.139*
25	0.159	1.002*	0.346*	0.455*	0.402*	0.517*	5.935*	1.674*	0.450	0.266	0.157	0.136
26	0.154	0.919*	0.341*	0.432*	0.380*	0.607*	5.459*	1.536*	0.786	0.262	0.153	0.145
27	0.149	0.840*	0.333*	0.409*	0.361*	0.741*	5.018*	1.409*	0.714	0.256	0.149	0.151
28	0.152	0.768*	0.348*	0.388*	0.346*	0.819*	4.609*	1.289*	0.684	0.249	0.150	0.152
29	0.153	0.704*	0.388*	0.367*		0.840*	4.968*	1.180*	0.590	0.243	0.145	0.189
30	0.153*	0.645*	0.400*	0.348*		0.925*	5.617*	1.083*	0.528	0.239	0.136	0.172
31	0.150*		0.380*	0.333*		1.052*		0.996*		0.230	0.135	

MONTHLY SUMMARY:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	4.353	11.276	13.031	12.934	12.165	13.816	131.818	130.796	16.601	9.874	5.463	4.538
TOTAL FLOW (cms days)	0.123	0.319	0.369	0.366	0.345	0.391	3.733	3.704	0.470	0.280	0.155	0.129
TOTAL DEPTH (in)	0.259	0.671	0.775	0.770	0.724	0.822	7.844	7.783	0.988	0.588	0.325	0.270
TOTAL DEPTH (cm)	0.658	1.704	1.969	1.955	1.839	2.088	19.923	19.769	2.509	1.492	0.826	0.686

ANNUAL SUMMARY:

Sum of Mean Daily Flow 366.665 cfs = 10.384 cms
Total Depth 21.818 in = 55.418 cm
Maximum Instantaneous Flow 8.835 cfs = 0.250 cms on May 5 at 24.00 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 6
WATERSHED AREA: 400 ACRES (161 HECTARES)

WATER YEAR 1972
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.153	0.171	0.162	0.171	0.201	0.727	1.113	2.797	0.478	0.301	0.179	0.130
2	0.144	0.170	0.179	0.173	0.202	0.689	1.248	2.688	0.455	0.296	0.176	0.131
3	0.141	0.168	0.165	0.171	0.212	0.832	1.444	2.873	0.435	0.287	0.169	0.131
4	0.141	0.162	0.162	0.162	0.217	0.691	1.546	3.332	0.416	0.279	0.165	0.131
5	0.141	0.157	0.163	0.166	0.217	0.622	1.905	3.570	0.400*	0.270	0.152	0.177
6	0.147	0.176	0.173	0.169	0.214	0.617	2.762	3.611	0.424	0.263	0.159	0.169
7	0.148	0.152	0.145*	0.171	0.209	0.615	3.253	3.455	0.574	0.261	0.155	0.147
8	0.146	0.161	0.000	0.172	0.205	0.602	2.957	3.486	0.592	0.252	0.152	0.139
9	0.147	0.161	0.019	0.171	0.201	0.722	2.740	2.969	0.806	0.255	0.156	0.137
10	0.144	0.162	0.161	0.169	0.198	1.191	2.512	2.578	0.895	0.245	0.154	0.140
11	0.143	0.172	0.163	0.174	0.198	1.882	2.344	2.367	0.799	0.237	0.148	0.148
12	0.143	0.189	0.165	0.176	0.198	1.964	2.281	2.208	0.675	0.229	0.145	0.156
13	0.143	0.186	0.166	0.172	0.203	2.242	2.094	2.122	0.625	0.223	0.148	0.153
14	0.146	0.179	0.166	0.172	0.199	2.411	1.910	2.039	0.586	0.220	0.160	0.143
15	0.149	0.172	0.164	0.172	0.199	2.394	1.789	1.938	0.549	0.215	0.181	0.142
16	0.152	0.161	0.162	0.172	0.199	2.690	1.767	1.771	0.522	0.211	0.158	0.144
17	0.154	0.157	0.163	0.176	0.203	3.463	1.826	1.607	0.486	0.207	0.153	0.145
18	0.156	0.157	0.167	0.176	0.207	4.325	1.881	1.411	0.461	0.206	0.153	0.143
19	0.172	0.160	0.165	0.194	0.206	4.015	1.908	1.257	0.440	0.217	0.152	0.162
20	0.201	0.160	0.165	0.199	0.227	3.275	1.938	1.131	0.415	0.219	0.156	0.158
21	0.171	0.160	0.166	0.302	0.255	2.896	2.185	1.026	0.405	0.223	0.152	0.150
22	0.163	0.160	0.208	0.278	0.262	3.063	2.363	0.976	0.395	0.212	0.142	0.150
23	0.160	0.160	0.226	0.245	0.263	3.691	2.541	0.901	0.390	0.209	0.143	0.149
24	0.160	0.163	0.190	0.222	0.259	3.196	2.794	0.835	0.375	0.206	0.138	0.165
25	0.159	0.162	0.187	0.211	0.246	2.671	2.803	0.776	0.413	0.202	0.136	0.172
26	0.166	0.163*	0.183	0.205	0.244	2.250	2.669	0.716	0.373	0.205	0.134	0.162
27	0.169	0.173	0.178	0.203	0.349	1.901	2.750	0.662	0.353	0.193	0.131	0.171
28	0.161	0.170	0.174	0.202	0.745	1.594	3.326	0.624	0.332	0.186	0.143	0.163
29	0.170	0.168	0.171*	0.199	1.132	1.353	3.614	0.584	0.320	0.186	0.152	0.159
30	0.170	0.165	0.170	0.196		1.175	3.115	0.540	0.310	0.185	0.143	0.157
31	0.171		0.170	0.197		1.110		0.511		0.183	0.135	
MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	4.829	4.973	4.996	5.938	7.870	60.868	69.380	57.359	14.698	7.085	4.719	4.526
TOTAL FLOW (cms days)	0.137	0.141	0.141	0.168	0.223	1.724	1.965	1.624	0.416	0.201	0.134	0.128
TOTAL DEPTH (in)	0.287	0.296	0.297	0.353	0.468	3.622	4.128	3.413	0.875	0.422	0.281	0.269
TOTAL DEPTH (cm)	0.730	0.752	0.755	0.897	1.189	9.200	10.486	8.669	2.222	1.071	0.713	0.684

ANNUAL SUMMARY:
Sum of Mean Daily Flow 247.242 cfs = 7.002 cms
Total Depth 14.712 in = 37.368 cm
Maximum Instantaneous Flow 4.547 cfs = 0.129 cms on March 18 at 20.00 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 6
WATERSHED AREA: 400 ACRES (161 HECTARES)

WATER YEAR 1973
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.158	0.175	0.160	0.219	0.344	0.315	0.658	0.992	0.269	0.155	0.100	0.100
2	0.157	0.177	0.160	0.219	0.341	0.367	0.642	0.909	0.260	0.156	0.096	0.092
3	0.153	0.180	0.160	0.216	0.341	0.377	0.653	0.885	0.256	0.153	0.103	0.089
4	0.156	0.225	0.160	0.214	0.337	0.386	0.734	0.909	0.246	0.152	0.098	0.086
5	0.151	0.209	0.159	0.210	0.334	0.395	0.867	0.850	0.230	0.148	0.092	0.083
6	0.150	0.184	0.157	0.206	0.310	0.408	0.940	0.791	0.222	0.143	0.088	0.082
7	0.148	0.179	0.155	0.206	0.269	0.415	0.934	0.741	0.216	0.140	0.088	0.167
8	0.147	0.185	0.152	0.204	0.263	0.421	0.917	0.732	0.207	0.137	0.086	0.124
9	0.160	0.182	0.150	0.200	0.256	0.430	0.911	0.663	0.206	0.135	0.083	0.104
10	0.213	0.181	0.149	0.198	0.251	0.429	0.936	0.611	0.195	0.132	0.083	0.099
11	0.217	0.182	0.160	0.194	0.251	0.427	1.031	0.562	0.189	0.128	0.081	0.096
12	0.176	0.181	0.164	0.192	0.249	0.425	1.268	0.520	0.187	0.128	0.079	0.095
13	0.165	0.176	0.162	0.200	0.244	0.424	1.743	0.485	0.186	0.127	0.073	0.091*
14	0.167	0.176	0.160	0.226	0.240	0.415	1.843	0.453	0.249	0.125	0.073	0.094*
15	0.179	0.178	0.160	0.238	0.235	0.415	1.665	0.430	0.217	0.122	0.073	0.095*
16	0.174	0.179	0.158	0.409	0.232	0.415	1.555	0.423	0.206	0.119	0.073	0.094*
17	0.169	0.202	0.159	0.399	0.232	0.452	1.534	0.410	0.234	0.117	0.073	0.099*
18	0.167	0.209	0.180	0.375	0.228	0.460	1.444	0.395	0.215	0.112	0.073	0.099*
19	0.166	0.196	0.277	0.375	0.224	0.464	1.330	0.377	0.200	0.122	0.072	0.107*
20	0.165	0.182	0.228	0.371	0.224	0.468	1.244	0.359	0.190	0.129	0.070	0.159*
21	0.162	0.175	0.362	0.368	0.224	0.475	1.178	0.335	0.185	0.128	0.059	0.149
22	0.162	0.182	0.632	0.368	0.224	0.488	1.166	0.319	0.178	0.120	0.073	0.126
23	0.162	0.174	0.417	0.364	0.227	0.497	1.240	0.314	0.181	0.121	0.077	0.129
24	0.162	0.169	0.338	0.361	0.230	0.546	1.312	0.337	0.179	0.120	0.080	0.207
25	0.162	0.170	0.280	0.361	0.228	0.658	1.321	0.353*	0.177	0.112*	0.088	0.175
26	0.162	0.204	0.257	0.358	0.230	0.756	1.295	0.303	0.172	0.110	0.086	0.143
27	0.163	0.170	0.248	0.354	0.239	0.759	1.345	0.294	0.169	0.104	0.086	0.131
28	0.164	0.163	0.232	0.354	0.270	0.732	1.324	0.286	0.162	0.097	0.084	0.127
29	0.164	0.186	0.226	0.351		0.696	1.205	0.276	0.161	0.096	0.083	0.124
30	0.162	0.168	0.224	0.347		0.678	1.083	0.270	0.159	0.098	0.083	0.122
31	0.163		0.222	0.347		0.671		0.273		0.099	0.097	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	5.126	5.498	6.808	9.004	7.276	15.264	35.317	15.857	6.104	3.886	2.551	3.485
TOTAL FLOW (cms days)	0.145	0.156	0.193	0.255	0.206	0.432	1.000	0.449	0.173	0.110	0.072	0.099
TOTAL DEPTH (in)	0.305	0.327	0.405	0.536	0.433	0.908	2.102	0.944	0.363	0.231	0.152	0.207
TOTAL DEPTH (cm)	0.775	0.831	1.029	1.361	1.100	2.307	5.338	2.397	0.923	0.587	0.386	0.527

ANNUAL SUMMARY:
Sum of Mean Daily Flow 116.177 cfs = 3.290 cms
Total Depth 6.913 in = 17.559 cm
Maximum Instantaneous Flow 1.896 cfs = 0.054 cms on April 13 at 24.00 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 6
WATERSHED AREA: 400 ACRES (161 HECTARES)

WATER YEAR 1974
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.136*	0.192	0.338	0.471	0.734	0.604	4.748	5.102	0.676	0.300	0.215	0.150
2	0.137	0.166	0.348	0.702*	0.694	0.586	4.048	5.119	0.651	0.300	0.226	0.151
3	0.138	0.154	0.344	0.659*	0.667	0.552	3.422	4.813	0.619	0.302	0.217	0.148
4	0.136	0.146	0.340	0.609*	0.640	0.542	2.938	4.537	0.643	0.297	0.214	0.145
5	0.134	0.156	0.335	0.493	0.609	0.585	2.611	4.518*	0.648	0.295	0.209	0.146
6	0.135	0.280	0.334	0.435*	0.583	0.655	2.786	4.395	0.610	0.292	0.241	0.147
7	0.215	0.265	0.357	0.317	0.568	0.616	2.803	4.016	0.584	0.291	0.237	0.145
8	0.164	0.246	0.361	0.331*	0.550	0.606	3.142	3.756	0.554	0.309	0.213	0.142
9	0.155	0.322	0.338	0.348*	0.531	0.604	3.783	3.334	0.530	0.349	0.204	0.142
10	0.149	0.842	0.337	0.343*	0.520	0.602	4.054	2.861	0.509	0.375	0.198	0.142
11	0.146	1.107	0.335	0.343*	0.510	0.605	4.105	2.440	0.490	0.378	0.193	0.142
12	0.144	1.979	0.334	0.340*	0.502	0.715	4.467	2.236	0.472	0.326	0.189	0.147
13	0.143	1.251	0.332	0.289	0.492	0.810	4.359	1.987	0.459	0.308	0.188	0.148
14	0.141	0.879	0.328	0.370	0.482	0.834	4.601	1.789	0.447	0.301	0.191	0.143
15	0.140	0.747	0.322	1.013	0.480	0.856	5.275	1.619	0.437	0.301	0.184	0.141
16	0.139	0.747	0.336	3.447	0.478	0.948	6.202	1.476	0.422	0.292	0.183	0.139
17	0.139	0.778	0.370	4.446	0.472	1.743	7.844	1.384	0.407	0.282	0.178	0.137
18	0.138	0.725	0.365	3.067	0.468	2.238	9.606	1.291	0.394	0.273	0.174	0.135
19	0.135	0.668	0.355	2.409	0.464	2.345	10.539	1.199	0.382	0.267	0.186	0.139*
20	0.137	0.627	0.351	2.020	0.455	2.229	10.035	1.153	0.404	0.257	0.219	0.146*
21	0.141	0.586	0.351	1.764	0.445	2.098	9.006	1.094	0.384	0.250	0.190	0.148*
22	0.139	0.537	0.355	1.566	0.440	2.003	8.790	1.049	0.366	0.244	0.182	0.149*
23	0.181	0.506	0.354	1.418	0.432	1.866	9.783	1.017	0.348	0.244	0.177	0.149*
24	0.168	0.472	0.349	1.295	0.427	1.801	10.956	0.986	0.338	0.244	0.175	0.149*
25	0.195	0.413	0.342	1.190	0.421	1.890	10.451	0.955	0.334	0.235	0.169	0.149*
26	0.156	0.361	0.337	1.088	0.420	2.338	8.189	0.910	0.338	0.235	0.166	0.148*
27	0.149	0.343	0.340*	1.002	0.418	3.103	5.812	0.860	0.330	0.233	0.162	0.146*
28	0.145	0.334	0.343	0.938	0.448	4.872	4.790	0.811*	0.321	0.226	0.160	0.147*
29	0.147	0.329	0.338	0.876		4.612	4.195	0.772	0.313	0.222	0.158	0.148*
30	0.144	0.328	0.325	0.817		4.849	4.541	0.750	0.304	0.222	0.154	0.146*
31	0.198		0.322	0.772		5.160		0.709		0.219	0.152	

MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	4.663	16.483	10.615	35.178	14.348	53.866	177.879	68.936	13.716	8.668	5.904	4.353
TOTAL FLOW (cms days)	0.132	0.467	0.301	0.996	0.406	1.525	5.038	1.952	0.388	0.245	0.167	0.123
TOTAL DEPTH (in)	0.277	0.981	0.632	2.093	0.854	3.205	10.585	4.102	0.816	0.516	0.351	0.259
TOTAL DEPTH (cm)	0.705	2.491	1.604	5.317	2.169	8.141	26.885	10.419	2.073	1.310	0.892	0.658

ANNUAL SUMMARY:
Sum of Mean Daily Flow 414.611 cfs = 11.742 cms
Total Depth 24.671 in = 62.664 cm
Maximum Instantaneous Flow 11.489 cfs = 0.325 cms on April 24 at 22.08 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 6
WATERSHED AREA: 400 ACRES (161 HECTARES)

WATER YEAR 1975
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.091	0.131	0.150*	0.134	0.206	0.118	0.213	1.270	1.018	0.289	0.142	0.134
2	0.093	0.133	0.142*	0.133	0.207	0.153	0.215	1.625	0.957	0.283	0.138	0.132
3	0.096	0.129	0.139	0.134	0.204	0.182	0.219	2.510	0.868	0.274	0.137	0.128
4	0.098	0.128	0.174	0.134	0.202	0.184	0.226	2.652	0.776	0.273	0.133	0.127
5	0.102	0.128	0.158	0.134	0.200	0.184	0.231	2.243	0.700	0.262	0.130	0.125
6	0.104	0.129	0.150	0.134	0.198	0.181	0.236	1.946	0.638	0.249	0.127	0.125
7	0.103	0.175	0.148	0.134	0.198	0.182	0.243	1.784	0.542	0.240	0.128	0.119
8	0.100	0.164	0.145	0.145	0.199	0.221	0.245	1.960	0.513	0.232	0.125	0.119
9	0.124	0.139	0.138	0.145	0.195	0.312	0.244	2.601	0.501	0.223	0.124	0.119
10	0.128	0.137	0.132	0.146	0.190	0.317	0.216	4.105	1.002	0.218	0.124	0.120
11	0.113	0.133	0.136	0.145	0.164	0.308	0.211	5.623	0.660	0.214	0.121	0.120
12	0.107	0.133	0.138	0.145	0.154	0.303	0.243	6.061	0.440	0.214	0.119	0.115
13	0.107	0.134	0.142	0.144	0.150	0.304	0.386	6.564	0.415	0.221	0.116	0.115
14	0.108	0.134	0.138	0.143	0.143	0.301	0.520	7.134	0.396	0.206	0.117	0.156
15	0.105	0.133	0.137	0.149	0.137	0.299	0.543	7.762	0.383	0.202	0.119	0.144
16	0.104	0.134	0.135	0.180	0.136	0.287	0.605	6.928	0.367	0.196	0.120	0.132
17	0.103	0.134	0.133	0.172	0.135	0.261	0.648	5.969	0.443	0.207	0.133	0.126
18	0.103	0.168	0.134	0.177	0.134	0.252	0.785	5.206	0.540	0.192	0.178	0.125
19	0.104	0.150	0.128	0.178	0.135	0.286	0.932	4.492	0.472	0.186	0.172	0.125
20	0.112	0.145	0.129	0.176	0.135	0.284	1.059	3.591	0.467	0.177	0.157	0.126
21	0.149	0.151	0.126*	0.174	0.130	0.273	1.236	3.018	0.427	0.174	0.149	0.125
22	0.138	0.160	0.125*	0.145	0.127	0.264	1.533	2.675	0.398	0.181	0.186	0.125
23	0.133	0.149	0.124*	0.132	0.126	0.261	1.970	2.448	0.380	0.168	0.202	0.120
24	0.134	0.150	0.124*	0.132	0.124	0.266	1.956	2.198	0.379	0.167	0.163	0.119
25	0.130	0.153*	0.125*	0.236	0.124	0.229	2.177	1.919	0.391	0.160	0.143	0.116
26	0.125	0.151*	0.127*	0.230	0.123	0.216	1.826	1.704	0.367	0.157	0.137	0.115
27	0.124	0.152*	0.129*	0.215	0.121	0.216	1.571	1.582	0.346	0.156	0.145	0.117
28	0.128	0.150*	0.133*	0.198	0.120	0.222	1.367	1.454	0.330	0.154	0.161	0.118
29	0.131	0.150*	0.134	0.186		0.226	1.238	1.338	0.316	0.168	0.142	0.118
30	0.125	0.151*	0.134	0.202		0.226	1.206	1.247	0.303	0.168	0.133	0.117
31	0.126		0.134	0.208		0.216		1.137		0.145	0.130	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	3.550	4.307	4.242	5.040	4.417	7.534	24.298	102.746	15.737	6.354	4.353	3.722
TOTAL FLOW (cms days)	0.101	0.122	0.120	0.143	0.125	0.213	0.688	2.910	0.446	0.180	0.123	0.105
TOTAL DEPTH (in)	0.211	0.256	0.252	0.300	0.263	0.448	1.446	6.114	0.936	0.378	0.259	0.221
TOTAL DEPTH (cm)	0.537	0.651	0.641	0.762	0.668	1.139	3.672	15.529	2.379	0.960	0.658	0.563

ANNUAL SUMMARY:
Sum of Mean Daily Flow 186.299 cfs = 5.276 cms
Total Depth 11.086 in = 28.157 cm
Maximum Instantaneous Flow 8.357 cfs = 0.237 cms on May 14 at 20.00 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 6
WATERSHED AREA: 400 ACRES (161 HECTARES)

WATER YEAR 1976
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.142	0.239	1.329	0.350	0.353	0.374	0.802	4.083	0.539	0.293	0.234	0.176
2	0.144	0.231	1.184	0.340	0.363	0.375	0.812	4.686	0.522	0.287	0.216	0.176
3	0.146	0.237	0.807	0.333	0.379	0.372	0.933	4.839	0.497	0.283	0.200	0.172
4	0.154	0.244	0.795	0.319	0.388	0.374	1.331	4.675	0.490	0.284	0.204	0.169
5	0.152	0.241	0.934	0.321	0.405	0.376	2.243	4.165	0.480	0.277	0.199	0.168
6	0.241	0.249	0.827	0.316	0.411	0.372	2.892	3.788	0.473	0.268	0.192	0.190
7	0.301	0.296	1.132	0.311	0.411	0.367	3.175	3.646	0.459	0.266	0.193	0.174
8	0.198	0.264	1.243	0.308	0.411	0.364	4.277	3.454	0.445	0.260	0.205	0.173
9	0.183	0.249	1.199	0.302	0.414	0.363	5.319	3.176	0.435	0.252	0.198	0.170
10	0.182	0.248	1.086	0.290	0.415	0.363	5.310	2.958	0.479	0.249	0.193	0.171
11	0.257	0.230	0.989	0.290	0.413	0.416	5.379	2.698	0.550	0.258	0.193	0.211
12	0.236	0.217	0.908	0.290	0.408	0.430	5.332	2.255	0.488	0.248	0.178	0.182
13	0.208	0.213	0.807	0.290	0.402	0.434	5.047	1.958	0.473	0.234	0.172	0.166
14	0.200	0.209	0.722	0.292	0.397	0.461	4.854	1.777	0.448	0.231	0.174	0.163
15	0.191	0.275	0.675	0.312	0.395	0.467	4.567	1.564	0.428	0.227	0.250	0.160
16	0.187	0.334	0.617	0.344	0.396	0.477	3.972	1.394	0.444	0.224	0.228	0.185
17	0.182	0.304	0.569	0.334	0.397	0.510	3.536	1.286	0.419	0.269	0.214	0.192
18	0.181	0.276	0.540	0.331	0.390	0.538	3.250	1.160	0.394	0.390	0.215	0.201
19	0.179	0.262	0.526	0.327	0.391	0.553	3.050	1.052	0.378	0.293	0.199	0.189
20	0.176	0.243	0.504	0.323	0.389	0.549	2.983	0.969	0.375	0.260	0.184	0.178
21	0.237	0.239	0.485	0.324	0.388	0.550	2.892	0.896	0.410	0.251	0.178	0.170
22	0.216	0.230	0.470	0.323	0.389	0.556	2.803	0.838	0.385	0.243	0.190	0.173
23	0.196	0.226	0.457	0.325	0.390	0.580	2.810	0.786	0.364	0.233	0.218	0.179
24	0.185	0.223	0.443	0.327	0.365	0.601	3.041	0.753	0.357	0.254	0.212	0.169
25	0.190	0.220	0.432	0.325	0.329	0.609	3.768	0.713	0.352	0.237	0.204	0.168
26	0.273	0.220	0.423	0.325	0.355	0.600	3.725	0.646	0.346	0.228	0.211	0.167
27	0.230	0.218	0.406	0.325	0.371	0.596	3.371	0.608	0.332	0.219	0.195	0.166
28	0.226	0.216	0.386	0.325	0.383	0.585	3.089	0.604	0.325	0.210	0.189	0.166
29	0.221	0.241	0.386	0.334	0.377	0.569	3.137	0.567	0.311	0.219	0.186	0.171
30	0.232	0.362	0.380	0.337		0.564	3.494	0.547	0.295	0.216	0.185	0.169
31	0.249		0.354	0.339		0.614		0.604		0.217	0.179	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	6.296	7.455	22.013	9.931	11.273	14.960	101.196	63.145	12.693	7.881	6.189	5.265
TOTAL FLOW (cms days)	0.178	0.211	0.623	0.281	0.319	0.424	2.866	1.788	0.359	0.223	0.175	0.149
TOTAL DEPTH (in)	0.375	0.444	1.310	0.591	0.671	0.890	6.022	3.757	0.755	0.469	0.368	0.313
TOTAL DEPTH (cm)	0.952	1.127	3.327	1.501	1.704	2.261	15.295	9.544	1.918	1.191	0.935	0.796

ANNUAL SUMMARY:
Sum of Mean Daily Flow 268.297 cfs = 7.598 cms
Total Depth 15.965 in = 40.551 cm
Maximum Instantaneous Flow 5.654 cfs = 0.160 cms on April 10 at 21.00 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 7
WATERSHED AREA: 56 ACRES (22 HECTARES)

WATER YEAR 1965
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.031*	0.056	0.067	0.148	0.200	0.186	0.217	1.426	0.217	0.073	0.039	0.028
2	0.031	0.086	0.070	0.147	0.211	0.187	0.227	1.181	0.203	0.071	0.041	0.027
3	0.031	0.056	0.068	0.142	0.202	0.188	0.264	0.964	0.191	0.067	0.043	0.026
4	0.029	0.053	0.064	0.139	0.188	0.189	0.278	0.916	0.180	0.065	0.040	0.026
5	0.023	0.052	0.063	0.138	0.188	0.190	0.299	0.829	0.170	0.061	0.038	0.027
6	0.021	0.051	0.061	0.136	0.187	0.190	0.320	0.764	0.162	0.060	0.038	0.027
7	0.021	0.050	0.062	0.138	0.185	0.189	0.333	0.697	0.153	0.057	0.036	0.028
8	0.029	0.050	0.062	0.137	0.183	0.188	0.349	0.600	0.146	0.056	0.036	0.029
9	0.032	0.051	0.062	0.137	0.181	0.191	0.367	0.485	0.138	0.056	0.036	0.027
10	0.032	0.056	0.060	0.139	0.178	0.195	0.371	0.491	0.131	0.053	0.034	0.024
11	0.031	0.055	0.055	0.140	0.178	0.199	0.378	0.511	0.124	0.052	0.038	0.016
12	0.031	0.053	0.059	0.140	0.180	0.200	0.395	0.505	0.120	0.050	0.058	0.014
13	0.032	0.053	0.061	0.140	0.181	0.201	0.427	0.519	0.129	0.048	0.043	0.015
14	0.031	0.054	0.063	0.140	0.181	0.200	0.463	0.513	0.121	0.046	0.033	0.015
15	0.050	0.054	0.063	0.138	0.181	0.202	0.531	0.499	0.117	0.048	0.031	0.021
16	0.034	0.052	0.063	0.136	0.180	0.203	0.647	0.492	0.119	0.055	0.030	0.019
17	0.032	0.050	0.065	0.137	0.180	0.202	0.705	0.480	0.116	0.055	0.027	0.017
18	0.032	0.047	0.068	0.137	0.180	0.202	0.643	0.431	0.109	0.053	0.028	0.018
19	0.031	0.044	0.070	0.137	0.179	0.204	1.007	0.383	0.102	0.052	0.047	0.019
20	0.031	0.049	0.071	0.137	0.177	0.205	1.949	0.367	0.096	0.057	0.045	0.019
21	0.031	0.047	0.071	0.137	0.175	0.207	1.834	0.368	0.090	0.055	0.047	0.019
22	0.031	0.043	0.274	0.136	0.175	0.208	1.708	0.373	0.087	0.051	0.043	0.018
23	0.031	0.044	0.285	0.135	0.170	0.208	1.583	0.372	0.087	0.049	0.038	0.018
24	0.031	0.062	0.259	0.137	0.168	0.208	1.538	0.357	0.087	0.046	0.034	0.016
25	0.031	0.076	0.215	0.140	0.168	0.210	1.485	0.334	0.083	0.046	0.033	0.014
26	0.032	0.069	0.179	0.144	0.170	0.213	1.451	0.320	0.083	0.046	0.032	0.014
27	0.033	0.066	0.172	0.149	0.213	0.215	1.420	0.294	0.081	0.043	0.031	0.014
28	0.034	0.064	0.165	0.156	0.186	0.216	1.394	0.272	0.076	0.042	0.030	0.014
29	0.033	0.064	0.165	0.182		0.217	1.568	0.254	0.073	0.041	0.029	0.014
30	0.033	0.068	0.159	0.191		0.217	1.614	0.248	0.070	0.038	0.029	0.014
31	0.039		0.146	0.196		0.217		0.227		0.038	0.028	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	0.979	1.675	3.366	4.488	5.123	6.246	25.764	16.472	3.661	1.630	1.133	0.597
TOTAL FLOW (cms days)	0.028	0.047	0.095	0.127	0.145	0.177	0.730	0.466	0.104	0.046	0.032	0.017
TOTAL DEPTH (in)	0.416	0.712	1.431	1.907	2.178	2.655	10.951	7.001	1.556	0.693	0.481	0.254
TOTAL DEPTH (cm)	1.057	1.808	3.634	4.845	5.531	6.743	27.814	17.783	3.952	1.760	1.223	0.644

ANNUAL SUMMARY:
Sum of Mean Daily Flow 71.134 cfs = 2.015 cms
Total Depth 30.234 in = 76.795 cm
Maximum Instantaneous Flow 2.140 cfs = 0.061 cms on April 20 at 13.00 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 7
WATERSHED AREA: 56 ACRES (22 HECTARES)

WATER YEAR 1966
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.016	0.038	0.077	0.061*	0.052*	0.041*	0.152	0.132	0.045	0.017	0.013	0.017
2	0.018	0.038	0.069	0.060*	0.051*	0.041*	0.145	0.139	0.041	0.019	0.013	0.017
3	0.018	0.039	0.061	0.060*	0.050*	0.041*	0.133	0.145	0.040	0.018	0.013	0.017
4	0.016	0.041	0.062	0.060*	0.049*	0.041*	0.126	0.152	0.041	0.017	0.014	0.016
5	0.016	0.049	0.063	0.066*	0.047*	0.041*	0.124	0.151	0.036	0.016	0.015	0.018
6	0.017	0.050	0.061	0.071*	0.046*	0.041*	0.122	0.148	0.034	0.016	0.014	0.017
7	0.017	0.049	0.059	0.068*	0.045*	0.041*	0.121	0.139	0.032	0.014	0.014	0.016
8	0.018	0.048	0.058	0.062*	0.043*	0.041*	0.120	0.128	0.032	0.014	0.014	0.016
9	0.018	0.049	0.058	0.059*	0.043*	0.041*	0.133	0.134	0.038	0.015	0.014	0.016
10	0.018	0.050	0.059	0.058*	0.042*	0.041*	0.179	0.127	0.035	0.016	0.013	0.015
11	0.018	0.053	0.059	0.058*	0.041	0.041*	0.215	0.114	0.031	0.015	0.014	0.015
12	0.027	0.052	0.058	0.058*	0.041*	0.041*	0.207	0.107	0.029	0.015	0.014	0.017
13	0.040	0.052	0.057	0.058*	0.041*	0.053*	0.189	0.103	0.027	0.014	0.014	0.018
14	0.041	0.069	0.063	0.058*	0.041*	0.058*	0.183	0.104	0.025	0.014	0.014	0.026
15	0.052	0.063	0.064*	0.057*	0.041*	0.047*	0.189	0.099	0.025	0.013	0.014	0.031
16	0.041	0.055	0.064*	0.057*	0.041*	0.041*	0.199	0.095	0.024	0.012	0.013	0.024
17	0.040	0.055	0.064*	0.057*	0.041*	0.041*	0.195	0.088	0.024	0.012	0.013	0.021
18	0.039	0.063	0.064*	0.057*	0.041*	0.041*	0.194	0.082	0.025	0.012	0.013	0.021
19	0.048	0.057	0.064*	0.057*	0.041*	0.041*	0.180	0.078	0.025	0.011	0.014	0.024
20	0.040	0.054	0.064*	0.056*	0.041*	0.041*	0.167	0.075	0.025	0.011	0.014	0.022
21	0.039	0.053	0.063*	0.056*	0.041*	0.041*	0.155	0.071	0.025	0.010	0.014	0.021
22	0.038	0.053	0.063*	0.056*	0.041*	0.041*	0.143	0.071	0.026	0.010	0.015	0.020
23	0.038	0.053	0.063*	0.056*	0.041*	0.041*	0.139	0.066	0.027	0.010	0.014	0.019
24	0.050*	0.052	0.063*	0.055*	0.041*	0.047*	0.139	0.062	0.028	0.009	0.014	0.019
25	0.063*	0.051	0.062*	0.055*	0.041*	0.065*	0.146	0.059	0.025	0.009	0.014	0.021
26	0.060*	0.051	0.062*	0.055*	0.041*	0.084*	0.150	0.055	0.023	0.010	0.020	0.022
27	0.059*	0.051	0.062*	0.055*	0.041*	0.098*	0.141	0.052	0.021	0.014	0.021	0.022
28	0.053	0.050	0.061*	0.054*	0.041*	0.112*	0.136	0.052	0.021	0.013	0.018	0.021
29	0.041*	0.080	0.061*	0.054*		0.128*	0.131	0.049	0.019	0.013	0.019	0.021
30	0.038	0.077	0.061*	0.054*		0.143*	0.130	0.046	0.019	0.013	0.018	0.021
31	0.038		0.061*	0.053*		0.152*		0.045		0.013	0.018	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	1.076	1.593	1.933	1.800	1.213	1.815	4.681	2.966	0.869	0.414	0.457	0.590
TOTAL FLOW (cms days)	0.030	0.045	0.055	0.051	0.034	0.051	0.133	0.084	0.025	0.012	0.013	0.017
TOTAL DEPTH (in)	0.457	0.677	0.821	0.765	0.516	0.771	1.990	1.261	0.370	0.176	0.194	0.251
TOTAL DEPTH (cm)	1.162	1.720	2.086	1.943	1.310	1.959	5.054	3.202	0.939	0.447	0.494	0.637

ANNUAL SUMMARY:
Sum of Mean Daily Flow 19.409 cfs = 0.550 cms
Total Depth 8.249 in = 20.953 cm
Maximum Instantaneous Flow 0.223 cfs = 0.006 cms on April 11 at 16.00 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 7
WATERSHED AREA: 56 ACRES (22 HECTARES)

WATER YEAR 1967
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.021	0.024	0.050	0.060*	0.044	0.030	0.045	0.120	0.209	0.061	0.034	0.023
2	0.027	0.024	0.045	0.059*	0.040	0.029	0.045	0.120	0.192	0.058	0.033	0.022
3	0.025	0.024	0.043	0.057*	0.039	0.026	0.046	0.126	0.181	0.060	0.033	0.022
4	0.023	0.024	0.041	0.030*	0.038	0.027	0.050	0.142	0.170	0.058	0.032	0.023
5	0.023	0.025	0.041	0.030*	0.034	0.027	0.057	0.160	0.166	0.055	0.032	0.023
6	0.022	0.031	0.037	0.029*	0.033	0.025	0.060	0.187	0.163	0.053	0.031	0.023
7	0.023	0.029	0.037	0.029*	0.033	0.024	0.065	0.250	0.156	0.052	0.031	0.023
8	0.023	0.027	0.036	0.029*	0.032	0.024	0.067	0.326	0.146	0.050	0.031	0.023
9	0.023	0.026	0.036	0.029*	0.031	0.024	0.073	0.420	0.142	0.049	0.030	0.023
10	0.024	0.027	0.039	0.029*	0.031	0.026	0.095	0.502	0.135	0.048	0.030	0.023
11	0.024	0.027	0.039	0.029*	0.030	0.027	0.110	0.456	0.132	0.047	0.029	0.046
12	0.031	0.036	0.037	0.030	0.030	0.024	0.118	0.421	0.127	0.046	0.029	0.047
13	0.026	0.034	0.037	0.035	0.030	0.024	0.122	0.393	0.118	0.045	0.029	0.044
14	0.027	0.033	0.037	0.035	0.030	0.024	0.130	0.368	0.112	0.044	0.028	0.039
15	0.027	0.036	0.034	0.035	0.029	0.024	0.121	0.368	0.107	0.044	0.028	0.037
16	0.027	0.070	0.034	0.032	0.029	0.032	0.116	0.388	0.104	0.045	0.027	0.037
17	0.027	0.048	0.033*	0.030	0.029	0.042	0.110	0.420	0.103	0.052	0.027	0.037
18	0.027	0.043	0.033*	0.029	0.028	0.039	0.111	0.424	0.098	0.048	0.026	0.036
19	0.027	0.041	0.033*	0.030	0.027	0.039	0.112	0.420	0.091	0.046	0.025	0.036
20	0.026	0.056	0.034*	0.031	0.030	0.038	0.107	0.404	0.101	0.045	0.025	0.035
21	0.029	0.054	0.033*	0.031	0.030	0.040	0.106	0.385	0.110	0.044	0.024	0.035
22	0.029	0.045	0.032*	0.031	0.030	0.040	0.105	0.369	0.097	0.043	0.024	0.034
23	0.031	0.041	0.032*	0.030*	0.030	0.045	0.110	0.341	0.090	0.041	0.024	0.035
24	0.031	0.040	0.031*	0.030*	0.030	0.050	0.113	0.322	0.085	0.040	0.024	0.034
25	0.031	0.040	0.030*	0.028	0.029	0.050	0.119	0.298	0.081	0.039	0.024	0.034
26	0.030	0.039	0.029*	0.028	0.027	0.049	0.123	0.267	0.076	0.039	0.024	0.034
27	0.030	0.038	0.028*	0.031	0.026	0.047	0.130	0.257	0.075	0.037	0.024	0.034
28	0.027	0.039	0.046*	0.043	0.027	0.047	0.133	0.242	0.071	0.036	0.024	0.034
29	0.024	0.049	0.066*	0.066		0.049	0.127	0.245	0.068	0.035	0.024	0.035
30	0.024	0.044	0.064*	0.060		0.046	0.122	0.229	0.065	0.035	0.023	0.069
31	0.024		0.062*	0.050		0.045		0.211		0.034	0.023	

MONTHLY SUMMARY:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	0.814	1.116	1.210	1.129	0.878	1.084	2.950	9.577	3.572	1.430	0.853	1.002
TOTAL FLOW (cms days)	0.023	0.032	0.034	0.032	0.025	0.031	0.084	0.271	0.101	0.040	0.024	0.028
TOTAL DEPTH (in)	0.346	0.474	0.514	0.480	0.373	0.461	1.254	4.071	1.518	0.608	0.363	0.426
TOTAL DEPTH (cm)	0.879	1.204	1.307	1.219	0.948	1.170	3.184	10.340	3.856	1.543	0.921	1.081

ANNUAL SUMMARY:
Sum of Mean Daily Flow 25.614 cfs = 0.725 cms
Total Depth 10.887 in = 27.653 cm
Maximum Instantaneous Flow 0.529 cfs = 0.015 cms on May 10 at 07.75 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 7
WATERSHED AREA: 56 ACRES (22 HECTARES)

WATER YEAR 1968
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.060	0.052	0.062	0.055	0.047	0.095	0.182	0.181	0.067*	0.032	0.020	0.032
2	0.067	0.051	0.062	0.054	0.047	0.096	0.212	0.177	0.066	0.029	0.020	0.030
3	0.069	0.050	0.062	0.054	0.048	0.099	0.226	0.174	0.066	0.028	0.020	0.028
4	0.048	0.050	0.063	0.054	0.048	0.100	0.236	0.172	0.064	0.028	0.020	0.025
5	0.052	0.050	0.063	0.053	0.047	0.109	0.267	0.167	0.063	0.026	0.020	0.023
6	0.049	0.051	0.061	0.053*	0.046	0.119	0.262	0.161	0.068	0.025	0.021	0.019
7	0.048	0.052	0.061	0.053*	0.045	0.118	0.255	0.154	0.066	0.024	0.021	0.016
8	0.047	0.052	0.060*	0.053*	0.045	0.117	0.241	0.147	0.063	0.023	0.020	0.016
9	0.047	0.055	0.059*	0.051*	0.045	0.116	0.225	0.141	0.063	0.028	0.024	0.016
10	0.046	0.060	0.060*	0.049	0.045	0.114	0.230	0.136	0.061	0.025	0.034	0.019
11	0.047	0.063	0.062	0.048	0.044	0.111	0.248	0.134	0.057	0.027	0.027	0.025
12	0.049	0.062	0.063*	0.048	0.044	0.112	0.246	0.139	0.055	0.023	0.026	0.025
13	0.047	0.058	0.063*	0.050	0.044	0.118	0.241	0.139	0.053	0.025	0.030	0.025
14	0.047	0.056	0.063*	0.050	0.044	0.116	0.235	0.132	0.053	0.023	0.055	0.029
15	0.047	0.055	0.063*	0.051	0.044	0.114	0.228	0.128	0.051	0.022	0.047	0.031
16	0.047	0.054	0.063*	0.052	0.043	0.115	0.223	0.121	0.049	0.021	0.034	0.031
17	0.047	0.053	0.062*	0.051	0.041	0.117	0.215	0.114	0.046	0.021	0.037	0.029
18	0.047	0.056	0.062*	0.050	0.052	0.114	0.208	0.111	0.045	0.022	0.040	0.029
19	0.047	0.055	0.062*	0.050	0.102	0.111	0.201	0.109	0.042	0.024	0.039	0.029
20	0.047	0.053	0.061*	0.050	0.175	0.110	0.193	0.121	0.043	0.024	0.048	0.032
21	0.053	0.053	0.060*	0.050	0.144	0.109	0.187	0.111	0.040	0.024	0.045	0.033
22	0.053	0.053	0.059*	0.050	0.128*	0.106*	0.181	0.108	0.048	0.024	0.045	0.030
23	0.058	0.052	0.058*	0.050	0.143	0.104	0.176	0.097	0.047	0.024	0.039	0.025
24	0.054	0.055	0.056*	0.049	0.142	0.110	0.174	0.087	0.042	0.024	0.040	0.022
25	0.052	0.052	0.067	0.049	0.125	0.120	0.171	0.115	0.041	0.024	0.043	0.020
26	0.051	0.052*	0.065	0.049	0.115	0.126	0.170	0.112	0.039	0.024	0.033	0.018
27	0.060	0.055*	0.062	0.049	0.106	0.126	0.169	0.105	0.034	0.024	0.030	0.016
28	0.084	0.060*	0.061	0.048*	0.101	0.132	0.169	0.100*	0.031	0.024	0.030*	0.014
29	0.059	0.061	0.058	0.049*	0.096	0.144	0.171	0.092*	0.036	0.022	0.026*	0.013
30	0.054	0.063	0.057	0.047		0.158	0.177	0.085*	0.036	0.021	0.037	0.011
31	0.053		0.055	0.047		0.166		0.079*		0.020	0.037	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	1.637	1.644	1.894	1.564	2.194	3.624	6.320	3.948	1.534	0.757	1.009	0.712
TOTAL FLOW (cms days)	0.046	0.047	0.054	0.044	0.062	0.103	0.179	0.112	0.043	0.021	0.029	0.020
TOTAL DEPTH (in)	0.696	0.699	0.805	0.665	0.932	1.540	2.686	1.678	0.652	0.322	0.429	0.303
TOTAL DEPTH (cm)	1.767	1.775	2.044	1.689	2.368	3.913	6.823	4.262	1.656	0.817	1.089	0.769

ANNUAL SUMMARY:
Sum of Mean Daily Flow 26.838 cfs = 0.760 cms
Total Depth 11.407 in = 28.973 cm
Maximum Instantaneous Flow 0.274 cfs = 0.008 cms on April 5 at 01.25 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 7
WATERSHED AREA: 56 ACRES (22 HECTARES)

WATER YEAR 1969
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.010	0.033	0.039	0.029*	0.021	0.031	0.318*	0.397*	0.165	0.091*	0.044*	0.026
2	0.009	0.034	0.039	0.029*	0.018	0.031	0.344*	0.364*	0.159	0.089*	0.042*	0.026
3	0.008	0.040	0.040	0.028*	0.017	0.031	0.369*	0.339*	0.152	0.086*	0.041*	0.027
4	0.008	0.037	0.041	0.027*	0.017	0.031	0.375*	0.322*	0.144	0.084*	0.040*	0.029
5	0.008	0.035	0.043	0.043*	0.017	0.031	0.407*	0.318*	0.139	0.081*	0.039*	0.029
6	0.008	0.035	0.043	0.062*	0.017	0.031	0.499*	0.334*	0.132	0.079*	0.038*	0.029
7	0.008	0.034	0.046	0.063*	0.017	0.031	0.513*	0.352*	0.126	0.077*	0.037*	0.029
8	0.008	0.034	0.044	0.064*	0.017	0.031	0.436*	0.350*	0.129	0.075*	0.036*	0.028
9	0.009	0.050	0.040	0.062*	0.017	0.031	0.407*	0.333*	0.121	0.073*	0.035*	0.027
10	0.009	0.039	0.044	0.060*	0.017	0.031	0.438*	0.315*	0.111	0.071*	0.034*	0.027
11	0.017	0.044	0.052	0.059*	0.017	0.031	0.472*	0.300*	0.101	0.069*	0.033*	0.029
12	0.025	0.060	0.046	0.057*	0.020	0.031	0.498*	0.287*	0.095	0.067*	0.032*	0.031
13	0.023	0.047	0.081	0.061*	0.022	0.030	0.537*	0.277*	0.088	0.065*	0.039*	0.032
14	0.021	0.038	0.076	0.066*	0.021	0.029	0.537*	0.267*	0.086	0.063*	0.049*	0.031
15	0.019	0.034	0.064	0.067*	0.022	0.029	0.493*	0.265*	0.086	0.061*	0.048*	0.031
16	0.018	0.030	0.045	0.067*	0.022	0.029	0.451*	0.263*	0.083	0.060*	0.046*	0.031
17	0.017	0.028	0.039	0.067*	0.022	0.031	0.471*	0.253*	0.082	0.058*	0.045*	0.030
18	0.017	0.029	0.038	0.067*	0.024	0.032	0.557*	0.244*	0.083	0.057*	0.044*	0.031
19	0.017	0.026	0.039	0.067*	0.024	0.030	0.575*	0.236*	0.083	0.055*	0.043*	0.037
20	0.021	0.023	0.039	0.068*	0.025	0.030	0.519*	0.227*	0.094	0.053*	0.042*	0.048
21	0.021	0.021	0.037	0.069*	0.025	0.031	0.502*	0.219*	0.092	0.052*	0.040*	0.039
22	0.021	0.025	0.033	0.067*	0.026	0.031	0.587*	0.247	0.091	0.050*	0.039*	0.036
23	0.021	0.022	0.031*	0.065*	0.027	0.031	0.727*	0.243	0.100	0.049*	0.038*	0.036*
24	0.022	0.020	0.032	0.063*	0.028	0.032	0.751*	0.233	0.137	0.047*	0.037*	0.037
25	0.022	0.018	0.032*	0.061*	0.029	0.033*	0.678*	0.218	0.114	0.046*	0.036*	0.036
26	0.022	0.018	0.034	0.042	0.029	0.035	0.616*	0.210	0.105	0.049*	0.029	0.035
27	0.023	0.021	0.035*	0.028	0.030	0.085*	0.564*	0.202	0.101	0.050*	0.026	0.034
28	0.024	0.024	0.032*	0.026	0.031	0.148*	0.517*	0.195	0.098*	0.049*	0.026	0.036
29	0.027	0.031	0.032*	0.024		0.169*	0.473*	0.187	0.096*	0.047*	0.026	0.036
30	0.031	0.035	0.031*	0.022		0.211*	0.433*	0.184	0.093*	0.046*	0.026	0.035
31	0.031		0.030*	0.021		0.271*		0.172		0.045*	0.026	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	0.545	0.966	1.301	1.602	0.617	1.692	15.063	8.351	3.290	1.943	1.154	0.970
TOTAL FLOW (cms days)	0.015	0.027	0.037	0.045	0.017	0.048	0.427	0.236	0.093	0.055	0.033	0.027
TOTAL DEPTH (in)	0.232	0.411	0.553	0.681	0.262	0.719	6.402	3.549	1.398	0.826	0.491	0.412
TOTAL DEPTH (cm)	0.589	1.043	1.404	1.730	0.666	1.827	16.262	9.015	3.552	2.098	1.246	1.047

ANNUAL SUMMARY:
Sum of Mean Daily Flow 37.494 cfs = 1.062 cms
Total Depth 15.936 in = 40.478 cm
Maximum Instantaneous Flow 0.791 cfs = 0.022 cms on April 23 at 24.00 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 7
WATERSHED AREA: 56 ACRES (22 HECTARES)

WATER YEAR 1970
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.036	0.035	0.033*	0.059*	0.089*	0.058	0.072	0.124	0.256	0.087	0.042*	0.037*
2	0.048	0.034	0.032*	0.058*	0.086*	0.059	0.072	0.161	0.252	0.065	0.041*	0.036*
3	0.036	0.034	0.033*	0.057*	0.084*	0.056	0.073	0.227	0.243	0.059	0.040*	0.035*
4	0.031	0.034	0.032*	0.055*	0.081*	0.055	0.074	0.298	0.225	0.051*	0.039*	0.041*
5	0.031	0.038	0.037*	0.053*	0.079*	0.055	0.079	0.461	0.211	0.057*	0.045*	0.048*
6	0.030	0.044	0.043*	0.054*	0.077*	0.055	0.102	0.622	0.210	0.056*	0.051*	0.047*
7	0.029	0.041	0.043*	0.055*	0.075*	0.056	0.119	0.743	0.201	0.054*	0.050*	0.046*
8	0.036	0.037	0.043*	0.056*	0.073*	0.062	0.118	0.661	0.196	0.052*	0.049*	0.054*
9	0.034	0.036	0.043*	0.056*	0.071*	0.061	0.124	0.638	0.198	0.051*	0.047*	0.057*
10	0.032	0.035	0.043*	0.056*	0.069*	0.061	0.171	0.623	0.187	0.063*	0.046*	0.051*
11	0.031	0.034	0.043*	0.056*	0.067*	0.061	0.188*	0.567	0.181	0.076*	0.031	0.051*
12	0.029	0.034	0.044*	0.056*	0.065*	0.061	0.174	0.519	0.177	0.074*	0.028	0.051*
13	0.029	0.034	0.046*	0.057*	0.054	0.061	0.167	0.431	0.179	0.072*	0.028	0.051*
14	0.030	0.035	0.048*	0.060*	0.044	0.066	0.159	0.397	0.185	0.070*	0.029	0.051*
15	0.030	0.036	0.048*	0.063*	0.042	0.070	0.152	0.397	0.182	0.068*	0.030*	0.058
16	0.030	0.037	0.048*	0.063*	0.043	0.071	0.147	0.444	0.171	0.066*	0.028*	0.059
17	0.030	0.037	0.048*	0.063*	0.064	0.071	0.142	0.540	0.158	0.064*	0.027*	0.056
18	0.030	0.042	0.048*	0.063*	0.058	0.070	0.140	0.575	0.153	0.063*	0.026*	0.049
19	0.030*	0.044	0.049*	0.066*	0.058	0.069	0.135	0.574*	0.150	0.061*	0.025*	0.076
20	0.029	0.043	0.051*	0.071*	0.059	0.069	0.129	0.561	0.145	0.059*	0.024*	0.069
21	0.029	0.044	0.065*	0.077*	0.059	0.071	0.125	0.523	0.138	0.057*	0.035*	0.065
22	0.029	0.046*	0.077*	0.085*	0.058	0.069	0.122	0.507	0.134*	0.055*	0.046*	0.064
23	0.029	0.042*	0.075*	0.102*	0.056	0.068	0.118	0.487	0.132*	0.054*	0.046*	0.065
24	0.030	0.041*	0.073*	0.140*	0.054	0.068	0.118	0.438	0.088	0.053*	0.046*	0.062
25	0.030	0.040*	0.071*	0.163*	0.053	0.068	0.116	0.390	0.071	0.051*	0.045*	0.061*
26	0.030	0.039*	0.069*	0.155*	0.051	0.069	0.114	0.371	0.073	0.050*	0.044*	0.060*
27	0.031	0.038*	0.068*	0.125*	0.050	0.071	0.111	0.369	0.092	0.049*	0.043*	0.058*
28	0.041	0.037*	0.066*	0.099*	0.050	0.072	0.111	0.346	0.097	0.047*	0.041*	0.056*
29	0.037	0.036*	0.063*	0.096*		0.072	0.112	0.315	0.122	0.046*	0.040*	0.054*
30	0.035	0.035*	0.061*	0.093*		0.072	0.112	0.292	0.105	0.044*	0.039*	0.053*
31	0.035		0.060*	0.091*		0.072		0.271		0.043*	0.038*	
MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	1.002	1.143	1.600	2.403	1.768	2.018	3.697	13.869	4.911	1.817	1.191	1.622
TOTAL FLOW (cms days)	0.028	0.032	0.045	0.068	0.050	0.057	0.105	0.393	0.139	0.051	0.034	0.046
TOTAL DEPTH (in)	0.426	0.486	0.680	1.021	0.752	0.858	1.571	5.895	2.088	0.772	0.506	0.689
TOTAL DEPTH (cm)	1.082	1.234	1.727	2.595	1.909	2.178	3.991	14.973	5.302	1.961	1.285	1.751

ANNUAL SUMMARY:
Sum of Mean Daily Flow 37.040 cfs = 1.049 cms
Total Depth 15.743 in = 39.988 cm
Maximum Instantaneous Flow 0.796 cfs = 0.023 cms on May 7 at 12.25 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 7
WATERSHED AREA: 56 ACRES (22 HECTARES)

WATER YEAR 1971
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.051*	0.063	0.142*	0.080*	0.107*	0.121*	0.182*	0.925*	0.211*	0.116	0.057	0.037
2	0.050*	0.063	0.138*	0.080*	0.123*	0.127*	0.182*	1.128*	0.203*	0.110	0.056	0.039
3	0.049*	0.063	0.134*	0.080*	0.132*	0.124*	0.190*	1.327*	0.197*	0.111	0.052	0.040
4	0.051*	0.061	0.131*	0.080*	0.133*	0.120*	0.201*	1.322*	0.190*	0.115	0.047	0.041
5	0.054*	0.074	0.127*	0.080*	0.134*	0.117*	0.225*	1.304*	0.182*	0.115	0.046	0.041
6	0.054*	0.082	0.123*	0.081*	0.134*	0.114*	0.274*	1.280*	0.176*	0.118	0.045	0.041
7	0.054*	0.081	0.120*	0.082*	0.134*	0.115*	0.388*	1.152*	0.170*	0.121	0.046	0.047
8	0.054*	0.077	0.117*	0.084*	0.132*	0.112*	0.484*	1.039*	0.164*	0.116	0.044	0.043*
9	0.055*	0.080*	0.113*	0.085*	0.129*	0.112*	0.489*	0.936*	0.158*	0.116	0.042	0.045*
10	0.058*	0.080*	0.109*	0.085*	0.129*	0.117*	0.494*	0.843*	0.153*	0.113	0.041	0.044*
11	0.059*	0.078*	0.106*	0.085*	0.129*	0.114*	0.495*	0.760*	0.149*	0.118	0.040	0.043*
12	0.057*	0.076*	0.103*	0.086*	0.127*	0.114*	0.464*	0.685*	0.145*	0.116	0.040	0.042*
13	0.055*	0.074*	0.100*	0.086*	0.127*	0.115*	0.438*	0.616*	0.141*	0.114	0.039	0.041*
14	0.054*	0.072*	0.098*	0.086*	0.131*	0.113*	0.460*	0.560*	0.137*	0.113	0.044	0.039*
15	0.053*	0.070*	0.095*	0.086*	0.139*	0.111*	0.545*	0.514*	0.133*	0.111	0.039	0.038*
16	0.051*	0.068*	0.092*	0.086*	0.147*	0.108*	0.625*	0.471*	0.129*	0.109	0.036	0.037*
17	0.050*	0.066*	0.090*	0.086*	0.151*	0.105*	0.660*	0.431*	0.126*	0.101	0.038	0.036*
18	0.053*	0.064*	0.088*	0.085*	0.150*	0.102*	0.665*	0.394*	0.117	0.098	0.039	0.035*
19	0.057*	0.064*	0.085*	0.084*	0.146*	0.099*	0.678*	0.361*	0.119	0.105	0.037	0.034*
20	0.058*	0.064*	0.082*	0.097*	0.142*	0.096*	0.749*	0.337*	0.116	0.107	0.037	0.033*
21	0.060*	0.062*	0.080*	0.108*	0.138*	0.093*	0.844*	0.320*	0.111	0.093	0.036	0.032*
22	0.060*	0.060*	0.078*	0.107*	0.134*	0.101*	0.893*	0.303*	0.110	0.087	0.037	0.031*
23	0.060*	0.066*	0.076*	0.106*	0.131*	0.112*	0.852*	0.289*	0.105	0.084	0.037	0.031*
24	0.060*	0.122*	0.075*	0.105*	0.127*	0.121*	0.767*	0.280*	0.101	0.082	0.037	0.030*
25	0.060*	0.174*	0.075*	0.102*	0.123*	0.127*	0.690*	0.271*	0.113	0.075	0.037	0.040*
26	0.058*	0.168*	0.076*	0.099*	0.120*	0.144*	0.621*	0.261*	0.156	0.075	0.038	0.051*
27	0.057*	0.162*	0.078*	0.096*	0.117*	0.161*	0.564*	0.252*	0.153	0.069	0.037	0.051*
28	0.055*	0.156*	0.080*	0.093*	0.114*	0.160*	0.641*	0.243*	0.148	0.066	0.037	0.050*
29	0.053*	0.151*	0.080*	0.091*		0.159*	0.777*	0.234*	0.136	0.062	0.036	0.050*
30	0.060	0.146*	0.080*	0.089*		0.167*	0.835*	0.226*	0.125	0.058	0.038	0.052*
31	0.063		0.080*	0.094*		0.178*		0.219*		0.056	0.037	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	1.719	2.686	3.050	2.778	3.677	3.778	16.373	19.283	4.374	3.051	1.272	1.214
TOTAL FLOW (cms days)	0.049	0.076	0.086	0.079	0.104	0.107	0.464	0.546	0.124	0.086	0.036	0.034
TOTAL DEPTH (in)	0.730	1.141	1.296	1.181	1.563	1.606	6.959	8.196	1.859	1.297	0.541	0.516
TOTAL DEPTH (cm)	1.855	2.899	3.293	2.999	3.969	4.079	17.676	20.818	4.722	3.294	1.373	1.311

ANNUAL SUMMARY:
Sum of Mean Daily Flow 63.255 cfs = 1.791 cms
Total Depth 26.885 in = 68.289 cm
Maximum Instantaneous Flow 1.384 cfs = 0.039 cms on May 3 at 24.00 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 7
WATERSHED AREA: 56 ACRES (22 HECTARES)

WATER YEAR 1972
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.051*	0.041	0.029*	0.053*	0.025	0.064	0.167	0.413	0.192	0.072	0.042	0.042
2	0.051*	0.041	0.028*	0.055*	0.022	0.066	0.176	0.424	0.179	0.070	0.041	0.042
3	0.050*	0.042	0.028*	0.058*	0.020	0.076	0.189	0.447	0.170	0.067	0.042	0.043
4	0.048*	0.044	0.027*	0.058*	0.019	0.063	0.202	0.503	0.164	0.066	0.042	0.043
5	0.046*	0.049	0.026*	0.058*	0.017	0.061	0.247	0.560	0.156	0.064	0.040	0.059
6	0.047	0.062	0.041*	0.058*	0.014	0.062	0.271	0.597	0.146	0.063	0.039	0.056
7	0.047	0.050	0.057*	0.056*	0.015	0.060	0.305	0.680	0.155	0.063	0.038	0.049
8	0.046	0.040	0.055*	0.054*	0.015	0.060	0.372	0.737	0.179	0.060	0.038	0.050
9	0.043	0.034	0.054*	0.053*	0.016	0.061	0.365	0.701	0.187	0.061	0.039	0.048
10	0.040	0.043	0.053*	0.052*	0.015	0.065	0.355	0.672	0.199	0.060	0.039	0.049
11	0.040	0.046	0.051*	0.050*	0.015	0.086	0.338	0.665	0.180	0.059	0.036	0.053
12	0.036	0.052	0.050*	0.049*	0.015	0.100	0.351	0.635	0.166	0.058	0.035	0.055
13	0.033	0.051	0.047*	0.047*	0.016	0.120	0.329	0.612	0.152	0.056	0.037	0.056
14	0.034	0.048	0.046*	0.046*	0.017	0.137	0.308	0.593	0.142	0.054	0.051	0.054
15	0.035	0.045	0.045*	0.045*	0.017	0.127	0.295	0.595	0.129	0.053	0.053	0.054
16	0.035	0.043	0.050*	0.050*	0.017	0.126	0.289	0.586	0.126	0.052	0.044	0.053
17	0.035	0.042	0.055*	0.058*	0.019	0.137	0.263	0.551	0.111	0.053	0.039	0.053
18	0.035	0.041*	0.055*	0.059*	0.020	0.176	0.254	0.528	0.098	0.055	0.037	0.053
19	0.038	0.041*	0.054*	0.063*	0.020	0.214	0.250	0.511	0.092	0.055	0.036	0.062
20	0.045	0.040*	0.053*	0.066*	0.021	0.214	0.247	0.482	0.087	0.055	0.037	0.059
21	0.039	0.039*	0.053*	0.064*	0.024	0.219	0.259	0.450	0.089	0.055	0.036	0.056
22	0.038	0.038*	0.059*	0.063*	0.023	0.250	0.267	0.423	0.095	0.054	0.036	0.054
23	0.037	0.037*	0.065*	0.061*	0.023	0.280	0.287	0.401	0.098	0.051	0.036	0.053
24	0.036	0.036*	0.066*	0.060*	0.024	0.260	0.310	0.380	0.092	0.048	0.036	0.055
25	0.036	0.035*	0.064*	0.058*	0.023	0.250	0.322	0.358	0.098	0.047	0.036	0.058
26	0.038*	0.034*	0.063*	0.056*	0.022	0.243	0.319	0.308	0.090	0.046	0.035	0.057
27	0.037	0.033*	0.061*	0.054*	0.057	0.217	0.338	0.270	0.085	0.045	0.035	0.059
28	0.036	0.032*	0.059*	0.053*	0.086	0.204	0.379	0.253	0.080	0.044	0.053	0.057
29	0.052	0.031*	0.058*	0.051*	0.090	0.190	0.448	0.232	0.076	0.043	0.048	0.056
30	0.042	0.030*	0.056*	0.029*		0.176	0.422	0.214	0.074	0.043	0.044	0.055
31	0.041		0.054*	0.028		0.168		0.203		0.042	0.043	
MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	1.268	1.237	1.562	1.667	0.724	4.532	8.925	14.983	3.888	1.713	1.244	1.590
TOTAL FLOW (cms days)	0.036	0.035	0.044	0.047	0.021	0.128	0.253	0.424	0.110	0.049	0.035	0.045
TOTAL DEPTH (in)	0.539	0.526	0.664	0.708	0.308	1.926	3.793	6.368	1.652	0.728	0.529	0.676
TOTAL DEPTH (cm)	1.368	1.335	1.686	1.800	0.782	4.893	9.635	16.176	4.197	1.849	1.343	1.717

ANNUAL SUMMARY:
Sum of Mean Daily Flow 43.333 cfs = 1.227 cms
Total Depth 18.418 in = 46.782 cm
Maximum Instantaneous Flow 0.773 cfs = 0.022 cms on May 8 at 08.00 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 7
WATERSHED AREA: 56 ACRES (22 HECTARES)

WATER YEAR 1973
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.054	0.054	0.049*	0.065*	0.074*	0.097*	0.111*	0.259	0.115	0.048	0.033	0.040
2	0.054	0.055	0.062*	0.064*	0.073*	0.106*	0.108*	0.251	0.112	0.047	0.035	0.038
3	0.053	0.055	0.062*	0.064*	0.072*	0.105*	0.108*	0.256	0.109	0.046	0.035	0.038
4	0.053	0.066	0.062*	0.066*	0.071*	0.102*	0.114*	0.263	0.105	0.044	0.034	0.037
5	0.053	0.063	0.062*	0.068*	0.071*	0.099*	0.125*	0.260	0.101	0.044	0.034	0.036
6	0.051	0.060	0.063*	0.068*	0.071*	0.096*	0.135*	0.256	0.099	0.043	0.034	0.035
7	0.051	0.059	0.064*	0.068*	0.071*	0.094*	0.135*	0.250	0.096	0.043	0.035	0.062
8	0.052	0.059	0.064*	0.067*	0.071*	0.093*	0.131*	0.253	0.092	0.042	0.034	0.048
9	0.053	0.059	0.063*	0.067*	0.071*	0.092*	0.131*	0.239	0.090	0.041	0.034	0.043
10	0.070	0.060	0.062*	0.068*	0.071*	0.093*	0.131*	0.230	0.088	0.039	0.035	0.042
11	0.071	0.060	0.063*	0.068*	0.071*	0.093*	0.135*	0.222	0.085	0.038	0.036	0.041
12	0.060	0.060	0.063*	0.069*	0.070*	0.091*	0.160	0.212	0.084	0.038	0.034	0.040
13	0.049	0.060	0.061*	0.089*	0.069*	0.089*	0.212	0.206	0.084	0.038	0.033	0.040
14	0.046	0.060	0.060*	0.102*	0.069*	0.089*	0.224	0.200	0.096	0.037	0.033	0.040
15	0.049	0.060	0.059*	0.091*	0.069*	0.089*	0.213	0.192	0.092	0.036	0.036	0.041
16	0.047	0.062	0.058*	0.110*	0.069*	0.090*	0.210	0.185	0.089	0.035	0.037	0.040
17	0.050	0.064	0.058*	0.126*	0.069*	0.096*	0.227	0.179	0.089	0.034	0.039	0.039
18	0.048	0.060	0.063*	0.111*	0.069*	0.098*	0.228	0.172	0.078	0.034	0.035	0.039
19	0.046	0.056	0.075*	0.099*	0.069*	0.096*	0.223	0.166	0.069	0.036	0.032	0.048
20	0.047	0.054	0.076*	0.093*	0.069*	0.098*	0.216	0.153	0.065	0.038	0.031	0.074
21	0.050	0.053	0.087*	0.091*	0.068*	0.100*	0.213	0.148	0.064	0.038	0.033	0.050
22	0.051	0.055	0.125*	0.090*	0.068*	0.103*	0.211	0.143	0.064	0.037	0.031	0.045
23	0.052	0.053	0.116*	0.089*	0.069*	0.104*	0.222	0.131	0.063	0.035	0.032	0.048
24	0.051	0.046	0.085*	0.089*	0.069*	0.107*	0.232	0.143	0.060	0.035	0.033	0.064
25	0.050	0.046	0.077*	0.086*	0.070*	0.114*	0.242	0.155	0.058	0.035	0.037	0.056
26	0.052	0.052	0.072*	0.082*	0.071*	0.125*	0.246	0.139	0.055	0.034	0.036	0.046
27	0.052	0.049	0.070*	0.079*	0.076*	0.130*	0.271	0.133	0.051	0.033	0.036	0.043
28	0.053	0.048	0.069*	0.078*	0.085*	0.127*	0.283	0.128	0.049	0.032	0.035	0.043
29	0.053	0.044	0.069*	0.077*		0.122*	0.276	0.123	0.049	0.033	0.034	0.043
30	0.054	0.039	0.068*	0.076*		0.118*	0.268	0.120	0.049	0.032	0.035	0.042
31	0.054		0.067*	0.075*		0.115*		0.118		0.032	0.042	

MONTHLY SUMMARY:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	1.628	1.667	2.153	2.534	1.986	3.172	5.740	5.886	2.403	1.175	1.073	1.341
TOTAL FLOW (cms days)	0.046	0.047	0.061	0.072	0.056	0.090	0.163	0.167	0.068	0.033	0.030	0.038
TOTAL DEPTH (in)	0.692	0.708	0.915	1.077	0.844	1.348	2.440	2.502	1.021	0.499	0.456	0.570
TOTAL DEPTH (cm)	1.758	1.799	2.325	2.736	2.144	3.424	6.197	6.355	2.594	1.268	1.158	1.448

ANNUAL SUMMARY:

Sum of Mean Daily Flow 30.758 cfs = 0.871 cms
Total Depth 13.073 in = 33.206 cm
Maximum Instantaneous Flow 0.288 cfs = 0.008 cms on April 27 at 16.50 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 7
WATERSHED AREA: 56 ACRES (22 HECTARES)

WATER YEAR 1974
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.042	0.061	0.101	0.099*	0.147	0.145	0.448	0.977	0.233	0.082	0.043	0.046
2	0.043	0.056	0.098	0.099*	0.141	0.139	0.433	1.003	0.222	0.080	0.045	0.047
3	0.042	0.055	0.098	0.099*	0.138	0.126	0.411	0.967	0.210	0.078	0.043	0.047
4	0.042	0.057	0.102*	0.099*	0.135	0.124	0.384	0.970	0.210	0.074	0.043	0.047
5	0.040	0.059	0.095	0.099*	0.130	0.125	0.376	0.983	0.211	0.075	0.042	0.051*
6	0.039	0.079	0.096	0.099*	0.125	0.125	0.389	0.997	0.195	0.076	0.053	0.049
7	0.050	0.072	0.107	0.100*	0.123	0.124	0.371	1.108	0.188	0.076	0.057	0.047
8	0.042	0.073	0.109	0.100*	0.121	0.123	0.375	1.165	0.179	0.082	0.051	0.046
9	0.040	0.084	0.108	0.100*	0.117	0.121	0.393	1.096	0.173	0.096	0.048	0.046
10	0.039	0.133	0.117	0.100*	0.115	0.120	0.392	0.994	0.167	0.099	0.048	0.047
11	0.039	0.160	0.102	0.100*	0.114	0.122	0.399	0.913	0.160	0.095	0.046	0.047
12	0.038	0.220	0.102	0.100*	0.112	0.134	0.410	0.860	0.153	0.081	0.044	0.048
13	0.039	0.161	0.103	0.100*	0.111	0.134	0.394	0.797	0.148	0.073	0.045	0.048
14	0.039	0.131	0.103	0.104*	0.109	0.133	0.395	0.711	0.142	0.072	0.045	0.049
15	0.039	0.114	0.102	0.171*	0.107	0.135	0.426	0.631	0.136	0.071	0.044	0.048
16	0.039	0.116	0.108	0.276	0.107	0.145	0.465	0.561	0.130	0.068	0.045	0.046
17	0.039	0.119	0.114	0.370	0.106	0.195	0.494*	0.513	0.124	0.064	0.042	0.046
18	0.039	0.116	0.109	0.326	0.106	0.218	0.581*	0.462	0.120	0.060	0.042	0.045
19	0.040	0.110	0.105	0.311	0.106	0.236	0.731*	0.431	0.116	0.059	0.047	0.046
20	0.042	0.105	0.104	0.294	0.105	0.234	0.771	0.401	0.121	0.058	0.059	0.047
21	0.042	0.101	0.104	0.282	0.103	0.231	0.806*	0.372	0.113	0.055	0.055	0.047
22	0.041	0.097	0.107	0.280	0.102	0.230	0.836	0.349	0.109	0.056	0.055	0.047
23	0.050	0.094	0.106	0.265	0.100	0.229	0.961*	0.330	0.105	0.055	0.052	0.047
24	0.050	0.092	0.105	0.229	0.098	0.228	1.011	0.319	0.101	0.053	0.051	0.047
25	0.053	0.091	0.104*	0.201	0.098	0.228	1.194	0.311	0.097	0.053	0.049	0.047
26	0.048	0.091	0.103*	0.189	0.096	0.240	1.046	0.295	0.094	0.051	0.048	0.048
27	0.046	0.092	0.102*	0.180	0.095	0.273	0.908	0.278	0.092	0.050	0.047	0.051
28	0.047	0.092	0.101*	0.171	0.107	0.341	0.809	0.265	0.089	0.046	0.046	0.050
29	0.048	0.093	0.100*	0.163		0.353	0.746	0.259*	0.087	0.047	0.047	0.048
30	0.047	0.095	0.100*	0.157		0.432*	0.840	0.249	0.084	0.046	0.047	0.048
31	0.063		0.099*	0.152		0.461		0.242		0.043	0.046	
MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	1.349	3.021	3.213	5.418	3.172	6.206	18.190	19.809	4.307	2.074	1.476	1.420
TOTAL FLOW (cms days)	0.038	0.086	0.091	0.153	0.090	0.176	0.515	0.561	0.122	0.059	0.042	0.040
TOTAL DEPTH (in)	0.573	1.284	1.366	2.303	1.348	2.638	7.731	8.419	1.831	0.882	0.627	0.604
TOTAL DEPTH (cm)	1.456	3.261	3.469	5.849	3.424	6.699	19.638	21.385	4.650	2.239	1.593	1.533

ANNUAL SUMMARY:
Sum of Mean Daily Flow 69.654 cfs = 1.973 cms
Total Depth 29.605 in = 75.197 cm
Maximum Instantaneous Flow 1.264 cfs = 0.036 cms on April 25 at 21.00 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 7
WATERSHED AREA: 56 ACRES (22 HECTARES)

WATER YEAR 1975
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.011	0.015	0.017	0.026*	0.022	0.010	0.011	0.057	0.161	0.038	0.018	0.018
2	0.011	0.016	0.017	0.025*	0.021	0.011	0.011	0.074	0.157	0.035	0.018	0.018
3	0.012	0.015	0.018	0.025*	0.021	0.012	0.010	0.115	0.144	0.033	0.018	0.018
4	0.012	0.015	0.023	0.024*	0.020	0.012	0.010	0.112	0.139	0.033	0.017	0.018
5	0.012	0.015	0.023	0.024*	0.022	0.012	0.010	0.095	0.131	0.031	0.016	0.018
6	0.012	0.015	0.024	0.024	0.023	0.011	0.010	0.086	0.124	0.030	0.017	0.017
7	0.012	0.021	0.024	0.023	0.023	0.011	0.011	0.084	0.116	0.030	0.017	0.017
8	0.011	0.019	0.024	0.026	0.022	0.012	0.011	0.088	0.110	0.028	0.016	0.017
9	0.013	0.016	0.024	0.025	0.022	0.013	0.011	0.101	0.103	0.026	0.016	0.018
10	0.013	0.016	0.024	0.025	0.022	0.013	0.011	0.157	0.097	0.026	0.016	0.017
11	0.012	0.016	0.024	0.025	0.021	0.013	0.012	0.247	0.092	0.026	0.015	0.017
12	0.011	0.016	0.024	0.025	0.021	0.013	0.015	0.284	0.084	0.025	0.015	0.017
13	0.011	0.015	0.025	0.025	0.022	0.013	0.016	0.355	0.078	0.026	0.015	0.017
14	0.013	0.015	0.024	0.026	0.022	0.013	0.018	0.508	0.074	0.024	0.022	0.022
15	0.013	0.015	0.024	0.028	0.018	0.013	0.020	0.702	0.070	0.023	0.018	0.020
16	0.013	0.015	0.025	0.029	0.016	0.012	0.021	0.711	0.069	0.023	0.016	0.019
17	0.013	0.015	0.026	0.030	0.015	0.012	0.023	0.642	0.079	0.024	0.017	0.018
18	0.013	0.019	0.025	0.030*	0.015	0.015	0.026	0.574	0.093	0.023	0.022	0.018
19	0.013	0.017	0.025	0.030*	0.015	0.021	0.030	0.512	0.080	0.022	0.024	0.018
20	0.013	0.016	0.026	0.030*	0.014	0.018	0.034	0.434	0.075	0.021	0.022	0.018
21	0.016	0.017	0.027	0.030*	0.013	0.017	0.039	0.378	0.065	0.020	0.020	0.018
22	0.015	0.017	0.026	0.031*	0.013	0.016	0.049	0.338	0.060	0.021	0.024	0.005
23	0.015	0.016	0.026*	0.032	0.012	0.015	0.057	0.323	0.055	0.020	0.027	0.017
24	0.014	0.016	0.027*	0.032	0.011	0.015	0.060	0.292	0.055	0.020	0.023	0.018
25	0.014	0.016	0.027*	0.043	0.010	0.014	0.065	0.255	0.057	0.019	0.020	0.018
26	0.014	0.015	0.028*	0.039	0.010	0.014	0.059	0.233	0.052	0.018	0.018	0.017
27	0.014	0.015	0.028*	0.031	0.010	0.014	0.055	0.220	0.048	0.018	0.018	0.017
28	0.015	0.016	0.028*	0.030	0.009	0.013	0.053	0.209	0.046	0.016	0.020	0.017
29	0.015	0.017	0.027*	0.028		0.013	0.051	0.197	0.043	0.018	0.019	0.017
30	0.014	0.017	0.027*	0.025		0.012	0.052	0.184	0.040	0.021	0.018	0.017
31	0.014		0.027*	0.024		0.011		0.171		0.019	0.018	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	0.406	0.483	0.764	0.874	0.485	0.416	0.862	8.740	2.598	0.758	0.578	0.523
TOTAL FLOW (cms days)	0.011	0.014	0.022	0.025	0.014	0.012	0.024	0.248	0.074	0.021	0.016	0.015
TOTAL DEPTH (in)	0.172	0.205	0.325	0.371	0.206	0.177	0.367	3.715	1.104	0.322	0.246	0.222
TOTAL DEPTH (cm)	0.438	0.521	0.825	0.943	0.524	0.449	0.931	9.435	2.805	0.818	0.624	0.564

ANNUAL SUMMARY:

Sum of Mean Daily Flow 17.486 cfs = 0.495 cms

Total Depth 7.432 in = 18.877 cm

Maximum Instantaneous Flow 0.793 cfs = 0.022 cms on May 15 at 20.00 hours

* Indicates some data were estimated during this day.

SILVER CREEK STUDY AREA
WATERSHED: 7
WATERSHED AREA: 56 ACRES (22 HECTARES)

WATER YEAR 1976
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.020	0.025	0.096	0.030	0.031*	0.041	0.027	0.360	0.096	0.037	0.023	0.018
2	0.021	0.027	0.053	0.031	0.030*	0.040	0.025	0.465	0.084	0.034	0.022	0.018
3	0.021	0.027	0.045	0.031	0.030*	0.040	0.027	0.640	0.077	0.034	0.021	0.018
4	0.022	0.028	0.050	0.030	0.030*	0.038	0.031	0.743	0.072	0.034	0.020	0.018
5	0.022	0.028	0.051	0.029	0.029*	0.036	0.040	0.697	0.065	0.032	0.020	0.017
6	0.032	0.029	0.047	0.030	0.030*	0.035	0.058	0.672	0.062	0.031	0.020	0.020
7	0.039	0.034	0.062	0.029	0.030*	0.033	0.068	0.682	0.062	0.030	0.020	0.018
8	0.028	0.031	0.061	0.030	0.030*	0.031	0.088	0.661	0.060	0.028	0.020	0.018
9	0.027	0.029	0.058	0.030	0.030*	0.030	0.130	0.593	0.058	0.027	0.021	0.018
10	0.027	0.028	0.053	0.030	0.030*	0.029	0.127	0.598	0.059	0.027	0.019	0.018
11	0.038	0.027	0.050	0.030	0.030*	0.028	0.159	0.607	0.066	0.026	0.019	0.025
12	0.039	0.028	0.048	0.031	0.031*	0.027	0.199	0.475	0.061	0.026	0.019	0.022
13	0.034	0.029	0.045	0.031	0.031*	0.026	0.197	0.458	0.066	0.025	0.018	0.019
14	0.032	0.028	0.043	0.030	0.032*	0.025	0.207	0.427	0.063	0.023	0.019	0.018
15	0.031	0.034	0.041	0.032	0.034*	0.024	0.212	0.365	0.064	0.023	0.026	0.018
16	0.030	0.036	0.040	0.031	0.035*	0.024	0.184	0.316	0.065	0.022	0.025	0.022
17	0.030	0.033	0.039	0.031	0.037*	0.024	0.169	0.280	0.062	0.025	0.023	0.022
18	0.029	0.033	0.039	0.030	0.039*	0.025	0.166	0.282	0.061	0.043	0.023	0.023
19	0.028	0.031	0.038	0.030	0.041*	0.024	0.168	0.250	0.058	0.033	0.022	0.022
20	0.027	0.034	0.038	0.030	0.042*	0.023	0.167	0.216	0.060	0.030	0.020	0.020
21	0.032	0.036	0.037	0.028	0.043*	0.022	0.167	0.184	0.061	0.029	0.019	0.019
22	0.029	0.036	0.037	0.027	0.044*	0.023	0.151	0.166	0.055	0.028	0.021	0.020
23	0.026	0.036	0.036	0.026	0.044*	0.024	0.157	0.160	0.051	0.028	0.023	0.020
24	0.025	0.036	0.036	0.025	0.043	0.023	0.178	0.153	0.048	0.030	0.021	0.020
25	0.025	0.035	0.035	0.023	0.043	0.023	0.281	0.137	0.048	0.025	0.020	0.019
26	0.030	0.035	0.035	0.022	0.043	0.022	0.272	0.125	0.046	0.022	0.022	0.019
27	0.027	0.033	0.034	0.021	0.044	0.022	0.279	0.116	0.045	0.021	0.020	0.019
28	0.026	0.033	0.032	0.021	0.043	0.022	0.256	0.114	0.044	0.020	0.020	0.019
29	0.025	0.033	0.033	0.021	0.042	0.022	0.259	0.109	0.042	0.021	0.019	0.021
30	0.025	0.032	0.033	0.022		0.023	0.277	0.101	0.040	0.021	0.019	0.021
31	0.025		0.032	0.021		0.024		0.107		0.020	0.019	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	0.875	0.946	1.379	0.867	1.039	0.852	4.726	11.258	1.801	0.856	0.645	0.589
TOTAL FLOW (cms days)	0.025	0.027	0.039	0.025	0.029	0.024	0.134	0.319	0.051	0.024	0.018	0.017
TOTAL DEPTH (in)	0.372	0.402	0.586	0.368	0.442	0.362	2.009	4.785	0.766	0.364	0.274	0.250
TOTAL DEPTH (cm)	0.944	1.022	1.489	0.936	1.122	0.920	5.102	12.154	1.945	0.924	0.696	0.636

ANNUAL SUMMARY:
Sum of Mean Daily Flow 25.833 cfs = 0.732 cms
Total Depth 10.980 in = 27.889 cm
Maximum Instantaneous Flow 0.841 cfs = 0.024 cms on December 1 at 16.00 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 11
WATERSHED AREA: 1624 ACRES (657 HECTARES)

WATER YEAR 1963
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	1.467	1.467	2.478	1.676	1.967	1.996	4.480	3.431	3.968	3.376	1.901	1.762
2	1.460	1.467	3.258	1.711	1.512	1.967	4.197	3.708	3.947	3.254	1.859	1.719
3	1.451	1.467	4.780	1.681	2.728	1.939	3.918	4.428	3.942	3.199	1.906	1.620
4	1.467	1.467	4.286	1.637	3.384	1.884	3.723	4.554	4.128	3.194	1.913	1.604
5	1.467	1.751	3.527	1.592	4.176	1.856	3.664	4.749	4.576	3.247	1.886	1.588
6	1.467	1.569	3.083	1.575	4.250	1.856	4.792	4.868	4.086	3.176	1.920	1.554
7	1.467	1.478	2.764	1.554	4.088	1.830	5.817	4.905	3.985	3.085	1.905	1.569
8	1.712	1.467	2.540	1.575	3.775	1.777	5.911	4.945	3.952	3.012	1.917	1.595
9	1.985	1.597	2.402	1.566	3.529	1.762	5.826	4.957	4.001	2.833*	1.836	1.589
10	2.832	1.741	2.270	1.534*	3.257	1.762	5.598	4.848	3.936	2.531	1.831	1.535
11	2.379	1.661	2.156	1.525*	2.998	1.756	5.307	4.787	3.869	2.481	1.805	1.478*
12	4.547	1.922	2.066	1.516*	2.838	1.734	4.937	4.719	3.777	2.512	1.781	1.507
13	3.533	2.007	2.007	1.507*	2.648	1.695	4.746	4.633	3.697	2.433	1.758	1.610
14	6.439	1.967	1.978	1.498*	2.540	1.697	4.935	4.480	3.759	2.248	1.746	1.580
15	4.419	1.900	2.051	1.489*	2.435	1.716	5.374	4.251	3.775	2.223	1.745	1.668
16	3.112	1.830	2.109	1.480*	2.367	1.676	5.083	4.023	3.624	2.178	1.707	1.904
17	2.547	1.777	2.178	1.471*	2.321	1.664	4.795	3.905	3.560	2.157	1.657	1.618
18	2.239	1.701	2.322	1.462*	2.237	1.651	4.435	3.895	3.435	2.133	1.632	1.562
19	2.084	1.658	2.288	1.453*	2.219	1.651	4.119	3.947	3.384	2.057	1.543	1.552
20	1.968	1.889	2.230	1.445*	2.175	1.670	3.865	4.010	3.362	2.041	1.497*	1.537
21	1.884	1.884	2.162	1.432*	2.113	1.760	3.693	3.989	3.772	2.073	1.510	1.525
22	1.830	1.884	2.098	1.415*	2.054	1.830	3.478	4.053	3.771	2.055	1.530	1.509
23	1.746	1.856	2.025	1.398*	2.024	1.994	3.271	4.230	3.650	2.021	1.570	1.531
24	1.639	1.856	1.956*	1.381*	2.024	1.968	3.153	4.273	3.908	1.943	1.701	1.505
25	1.592	1.856	1.928*	1.365*	1.996	1.875	3.081	4.139	3.993	1.986	1.749	1.471
26	1.557	2.372	1.895*	1.348*	2.066	1.895	3.071	4.117	3.875	1.946	1.730	1.457
27	1.557	3.220	1.862*	1.332*	1.996	2.522	3.200	4.139	3.746	1.952	1.659	1.441
28	1.534	3.389	1.846	1.320*	1.996	4.712	3.085	4.194	3.544	1.937	1.572	1.432
29	1.511	3.007	1.814	1.312*		4.568	3.123	4.117	3.594	1.895	1.619	1.419
30	1.498	2.686	1.772	1.304		4.718	3.252	4.031	3.481	1.878	1.622	1.397
31	1.475		1.721	1.590		4.658		3.989		1.922	1.667	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	67.863	57.792	73.849	46.140	73.712	68.040	127.929	133.313	114.097	74.979	53.676	46.838
TOTAL FLOW (cms days)	1.922	1.637	2.091	1.307	2.088	1.927	3.623	3.775	3.231	2.123	1.520	1.326
TOTAL DEPTH (in)	0.995	0.847	1.082	0.676	1.080	0.997	1.875	1.954	1.672	1.099	0.787	0.686
TOTAL DEPTH (cm)	2.526	2.151	2.749	1.718	2.744	2.533	4.762	4.963	4.247	2.791	1.998	1.744

ANNUAL SUMMARY:
Sum of Mean Daily Flow 938.226 cfs = 26.571 cms
Total Depth 13.751 in = 34.927 cm
Maximum Instantaneous Flow 8.220 cfs = 0.233 cms on October 14 at 6.00 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 11
WATERSHED AREA: 1624 ACRES (657 HECTARES)

WATER YEAR 1964
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	1.401	1.308	1.228	1.129	1.088	1.054	3.068	3.897	3.264	3.634*	2.285	2.056*
2	1.404	1.300	1.236	1.195	1.074	1.048	2.610	3.646	3.296	3.542*	2.214	2.017*
3	1.393	1.304	1.268	1.122*	1.058*	1.036	2.179	3.372	3.227	3.435*	2.152	1.940*
4	1.393	1.427	1.161	1.112*	1.038*	1.064	2.251	3.210	3.250	3.512*	2.092	1.830*
5	1.463	1.356	1.197	1.119*	1.022	1.068	2.453	3.185	3.487	3.500*	2.048*	1.762*
6	1.473	1.473	1.242	1.136	1.015	1.051	2.205	3.337	3.439	3.295*	2.023*	1.746*
7	1.408	1.330	1.200	1.116*	1.015	1.045	2.023	3.689	3.586	3.225	2.044*	1.748*
8	1.389	1.470	1.202	1.081*	1.032	1.045	2.145	3.724	4.316	3.123	2.033*	1.621*
9	1.415	1.498	1.204*	1.081*	1.051	1.038	2.488	3.737	4.265	3.060	1.997*	1.512*
10	1.406	1.400	1.201*	1.081*	1.068	1.035	2.917	4.123	4.161	2.984	1.962*	1.657*
11	1.378	1.365	1.201*	1.081*	1.081	1.061	2.807	4.270	4.205	2.904	1.929*	1.520
12	1.363	1.340	1.201*	1.081*	1.081	1.061	2.509	4.459	4.336	2.861	1.918*	1.529
13	1.366	1.324	1.201*	1.081*	1.074	1.035	2.245	5.240	4.276	2.885	1.925*	1.529
14	1.356	1.387	1.197*	1.081*	1.074	1.032	2.195	5.231	4.227	2.831	1.915*	1.500
15	1.331	1.382	1.205	1.081*	1.081	1.048	2.490	5.233	4.141	2.775	1.894*	1.502
16	1.307	1.306	1.270	1.081*	1.081	1.068	2.711	5.233	4.278	2.710	1.880*	1.511
17	1.292	1.300	1.226	1.081	1.081	1.096	2.515	5.016	4.049	2.657	1.807*	1.493
18	1.289	1.296	1.216	1.074	1.078	1.147	2.302	5.040	4.034	2.598	1.766	1.494
19	1.319	1.290	1.201	1.102	1.064	1.132	2.244	5.394	4.277	2.565	1.926*	1.507
20	1.300	1.307	1.195	1.177	1.051	1.194	2.322	5.424	4.518	2.543	1.846*	1.541*
21	1.296	1.280	1.162*	1.119	1.051	1.258	2.486	5.247	4.931	2.507	1.772*	1.548*
22	1.282	1.261	1.150*	1.084	1.048	1.246	2.525	4.922	4.931	2.495	1.728*	1.502*
23	1.557	1.284	1.138	1.081	1.048	1.234	2.382	4.529	4.861	2.440	1.683*	1.475*
24	1.324	1.311	1.120	1.088	1.054*	1.223	2.238	4.186	4.681	2.392	1.666*	1.467*
25	1.387	1.295	1.128	1.134	1.054*	1.216	2.206	3.927	4.553	2.364	1.674*	1.445*
26	1.288	1.323	1.100	1.119	1.054*	1.201	2.168	3.743	4.432	2.317	1.848*	1.419*
27	1.273	1.354	1.122	1.105	1.054*	1.233	2.159	3.605	4.301	2.288	1.822*	1.423*
28	1.261	1.292	1.127	1.098	1.054*	1.273	2.370	3.647	4.142	2.318	1.921*	1.423*
29	1.285	1.249	1.088	1.095	1.054	1.371	2.951	3.517	3.969*	2.359	1.821*	1.428*
30	1.314	1.231	1.098	1.101		1.747	3.715	3.388	3.787*	2.387	1.741*	1.436*
31	1.316		1.098	1.098		2.467		3.307		2.274	2.086*	

MONTHLY SUMMARY:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	42.028	40.044	36.580	34.211	30.680	36.825	73.880	130.476	123.223	86.781	59.419	47.580
TOTAL FLOW (cms days)	1.190	1.134	1.036	0.969	0.869	1.043	2.092	3.695	3.490	2.458	1.683	1.347
TOTAL DEPTH (in)	0.616	0.587	0.536	0.501	0.450	0.540	1.083	1.912	1.806	1.272	0.871	0.697
TOTAL DEPTH (cm)	1.565	1.491	1.362	1.274	1.142	1.371	2.750	4.857	4.587	3.231	2.212	1.771

ANNUAL SUMMARY:
Sum of Mean Daily Flow 741.727 cfs = 21.006 cms
Total Depth 10.871 in = 27.612 cm
Maximum Instantaneous Flow 5.737 cfs = 0.162 cms on May 19 at 17.00 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 11
WATERSHED AREA: 1624 ACRES (657 HECTARES)

WATER YEAR 1965
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	1.436*	1.336	1.495	2.471	5.823	4.122	2.550	11.719	8.610	3.612	2.210	1.814
2	1.428*	1.386	1.461	2.288	4.809	3.764	3.520	10.909	8.425	3.462	2.254	1.792
3	1.419*	1.335	1.373	2.206	4.104	3.474	3.966	10.202	8.240	3.379	2.284	1.789
4	1.410*	1.324	1.324	2.113	3.685	3.245	4.353	9.480	8.100	3.334	2.218	1.773
5	1.402*	1.312	1.262	2.113	3.490	3.123	5.081	8.993	7.923	3.289	2.158	1.767
6	1.394*	1.304	1.205*	2.407	3.388	3.081	5.383	7.376*	7.807	3.227	2.123	1.782
7	1.385*	1.300	1.416*	2.568	3.246	3.158	5.439	6.548*	7.693	3.124	2.094	1.777
8	1.430	1.300	1.435	2.579	3.090	3.335	5.580	6.100	7.470	3.026	2.069	2.278
9	1.436	1.308	1.381	2.477	2.903	3.481	5.923	5.784	7.250	3.007	2.060	1.890
10	1.428	1.360	1.381	2.374	2.693	3.576	5.871	5.791	6.858	2.929	2.054	1.810
11	1.411	1.336	1.361	2.270	2.540*	3.624	5.610	6.155	6.514	2.877	2.025	1.772
12	1.389	1.308	1.320*	2.144	2.415	3.548	5.314	6.862	6.503	2.884	2.216	1.756
13	1.381	1.292	1.324*	2.083	2.347	3.389	5.655	8.133	5.958	2.819	2.211	1.773
14	1.369	1.273	1.358	2.077	2.276	3.280	6.408	8.540	5.806	2.780	2.030	1.847
15	1.472	1.261*	1.376	2.054	2.199	3.236	7.167	8.444	5.551	2.732	1.998	2.004
16	1.445	1.257*	1.324*	2.013	2.156	3.218	8.681	8.444	5.790	2.709	1.990	1.916
17	1.406	1.253*	1.312*	1.978	2.125	3.149*	9.721	8.316	5.368	2.714	2.038	1.808
18	1.394	1.261*	1.265	1.967	2.101	2.999*	8.370	7.855	5.121	2.715	2.007	1.782
19	1.385	1.265	1.341	1.967	2.126	2.838*	9.086	7.903	4.894	2.628	2.043	1.767
20	1.365	1.253	1.422	1.967	2.254	2.722	23.288*	7.856	4.695	2.602	2.042	1.756
21	1.348	1.242	2.051	1.967	2.559	2.648	20.100*	7.842	4.515	2.660	2.141	1.751
22	1.340	1.246	7.039	1.961	2.745	2.554	12.652	8.044	4.341	2.570	2.103	1.751
23	1.316	1.257	10.589	1.999	2.722	2.416	10.256	8.375	4.227	2.514	2.064	1.741
24	1.296	1.581	8.399	2.247	2.648	2.308*	9.650	8.271	4.437	2.466	2.036	1.726
25	1.288	1.773	7.637	2.193	2.582	2.256*	9.511	7.972	3.999	2.416	2.055	1.716
26	1.284	1.353	5.212	2.156	2.606	2.218	9.557	7.788	3.926	2.407	2.055	1.701
27	1.288	1.292	4.614	2.131	3.596	2.175	9.721	7.616	3.793	2.366	1.989	1.671
28	1.296	1.284	4.090	2.264	4.485	2.113	10.189	7.560	3.663	2.329	1.988	1.651
29	1.300	1.292	3.480	3.868		2.077	11.489	7.788	3.582	2.299	1.931	1.651
30	1.304	1.427	3.059	5.489		2.051	12.155	8.181	3.602	2.283	1.899	1.642
31	1.308		2.713	6.320		2.168		8.486		2.234	1.846	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	42.553	39.771	86.018	76.714	83.715	91.348	252.246	249.335	174.660	86.396	64.231	53.655
TOTAL FLOW (cms days)	1.205	1.126	2.436	2.173	2.371	2.587	7.144	7.061	4.946	2.447	1.819	1.520
TOTAL DEPTH (in)	0.624	0.583	1.261	1.124	1.227	1.339	3.697	3.654	2.560	1.266	0.941	0.786
TOTAL DEPTH (cm)	1.584	1.481	3.202	2.856	3.116	3.401	9.390	9.282	6.502	3.216	2.391	1.997

ANNUAL SUMMARY:
Sum of Mean Daily Flow 1300.643 cfs = 36.834 cms
Total Depth 19.062 in = 48.419 cm
Maximum Instantaneous Flow 27.291 cfs = 0.773 cms on April 20 at 12.00 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 11
WATERSHED AREA: 1624 ACRES (657 HECTARES)

WATER YEAR 1966
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	1.632	1.336	1.300	1.168	1.172	1.227	3.355	2.373	2.008	1.622	1.339	1.238
2	1.613	1.324	1.312	1.183	1.152	1.333	3.498	2.443	1.951	1.624	1.368	1.227
3	1.603	1.316	1.324	1.212	1.155	1.773	2.985	2.536	1.913	1.608	1.364	1.228
4	1.589	1.353	1.324	1.231	1.171	2.794	2.682	2.670	1.884	1.583	1.360	1.217
5	1.569	1.340	1.328	1.278	1.185	1.750	2.553	2.781	1.859	1.566	1.349	1.216
6	1.569	1.344	1.324	1.678	1.191	1.177	2.660	2.885	1.824	1.544	1.335	1.208
7	1.561	1.348	1.308	1.464	1.186	1.222	2.906	2.903	1.803	1.521	1.337	1.199
8	1.560	1.344	1.296	1.424	1.160	1.203	3.191	2.863	1.803	1.502	1.332	1.208
9	1.552	1.340	1.288	1.361	1.160	1.364	3.378	2.837	1.824	1.493	1.320	1.188
10	1.547	1.351	1.284	1.308	1.149	1.638	3.426	2.829	1.955	1.489	1.321	1.177
11	1.543	1.411	1.284	1.292	1.150*	1.664	3.601	2.796	1.882	1.487	1.316	1.172
12	1.538	1.367	1.284	1.280	1.152*	1.612	3.380	2.709	1.816	1.474	1.313	1.195
13	1.533	1.365	1.280	1.273	1.150*	1.749	3.056	2.611	1.767	1.472	1.325	1.229
14	1.527	1.378	1.265	1.265	1.150*	1.852	2.897	2.608	1.746	1.465	1.316	1.425
15	1.689	1.365	1.246	1.253	1.150*	1.859	2.902	2.506	1.738	1.445	1.301	1.405
16	1.567	1.344	1.231	1.227	1.150	1.877	3.071	2.456	1.724	1.432	1.286	1.292
17	1.556	1.365	1.223	1.208	1.153	1.737	3.106	2.369	1.714	1.438	1.283	1.248
18	1.522	1.444	1.216	1.212	1.157	1.603	2.898	2.315	1.706	1.430	1.274	1.232
19	1.555	1.380	1.204	1.212	1.150	1.586	2.689	2.272	1.706	1.416	1.270	1.238
20	1.529	1.356	1.197	1.208	1.167	1.524	2.575	2.236	1.760	1.405	1.265	1.242
21	1.516	1.356	1.190	1.204	1.152	1.489	2.514	2.206	1.716	1.386	1.253	1.227
22	1.511	1.352	1.182	1.197	1.153	1.462*	2.354	2.266	1.715	1.389	1.243	1.240
23	1.507	1.344	1.166	1.206	1.158	1.462	2.298	2.237	1.758	1.380	1.233	1.206
24	1.498	1.336	1.206	1.193	1.171	1.441	2.271	2.199	1.798	1.374	1.221	1.217
25	1.437	1.328	1.205	1.129	1.191	1.515	2.409	2.162	1.701	1.372	1.221	1.212
26	1.365	1.320	1.182	1.181	1.210	1.778	2.522	2.142	1.661	1.371	1.377	1.230
27	1.348	1.316	1.201	1.189	1.231	2.134	2.586	2.125	1.653	1.362	1.320	1.204
28	1.348	1.308	1.240	1.204	1.238	2.367	2.568	2.131	1.636	1.348	1.283	1.179
29	1.348	1.300	1.240	1.208		2.557	2.488	2.125	1.637	1.340	1.277	1.173
30	1.344	1.300	1.212	1.208		2.791	2.412	2.090	1.630	1.339	1.302	1.168
31	1.340		1.197	1.216		3.184		2.083		1.333	1.251	

MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	46.916	40.431	38.739	38.872	32.713	54.724	85.229	75.764	53.286	45.009	40.356	36.840
TOTAL FLOW (cms days)	1.329	1.145	1.097	1.101	0.926	1.550	2.414	2.146	1.509	1.275	1.143	1.043
TOTAL DEPTH (in)	0.688	0.593	0.568	0.570	0.479	0.802	1.249	1.110	0.781	0.660	0.591	0.540
TOTAL DEPTH (cm)	1.747	1.505	1.442	1.447	1.218	2.037	3.173	2.820	1.984	1.676	1.502	1.371

ANNUAL SUMMARY:
Sum of Mean Daily Flow 588.879 cfs = 16.677 cms
Total Depth 8.631 in = 21.922 cm
Maximum Instantaneous Flow 5.073 cfs = 0.144 cms on March 4 at 11.25 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED 11
WATERSHED AREA: 1624 ACRES (657 HECTARES)

WATER YEAR 1967
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	1.143	1.136	1.323	1.172	2.325	1.588	1.889	2.460	4.562	2.728	1.969	1.436
2	1.220	1.136	1.297	1.157	2.063	1.642	1.840	2.402	4.188	2.704	1.929	1.432
3	1.205	1.136	1.410	1.154	1.874	1.585	1.840	2.364	3.999	2.688	1.895	1.422
4	1.143	1.136	1.298	1.214	1.767	1.516	1.917	2.363	3.960	2.676	1.870	1.425
5	1.143	1.136	1.505	1.231	1.682	1.462	2.019	2.501	3.860	2.626	1.893	1.408
6	1.126	1.150	1.324	1.167	1.888	1.415	2.054	2.858	4.020	2.593	1.830	1.464
7	1.112	1.157	1.257	1.150	1.850	1.381	2.242	3.692	4.074	2.549	1.810	1.434
8	1.108	1.143	1.194*	1.157	1.547	1.381	2.469	5.182	3.931	2.508	1.798	1.418
9	1.108	1.140	1.154*	1.164	1.529	1.385	2.497	6.723	3.843	2.513	1.805	1.427
10	1.115	1.143	1.154	1.164	1.502	1.465	2.634	6.850	3.802	2.539	1.784	1.390
11	1.122	1.140	1.173	1.175	1.467	1.471	2.730	6.061	3.752	2.420	1.750	1.541
12	1.252	1.245	1.250	1.186	1.436	1.484	2.722	4.975	3.725	2.405	1.734	1.538
13	1.216	1.283	1.402	1.205	1.484	1.502	2.686	4.184*	3.633	2.406	1.717	1.462
14	1.216	1.217	1.437	1.216	1.424	1.507	2.747	3.639*	3.594	2.356	1.708	1.419
15	1.193	1.157	1.381	1.283	1.381	1.507	2.575	3.579*	3.486	2.310	1.690	1.401
16	1.172	1.571	1.381	1.277	1.381	1.736	2.450	3.875*	3.392	2.264	1.666	1.384
17	1.161	1.239	1.317	1.246	1.385	2.752	2.341	5.407*	3.393	2.610	1.641	1.373
18	1.154	1.164	1.242	1.238	1.365	2.893	2.382	7.064	3.359	2.375	1.627	1.356
19	1.147	1.147	1.227	1.281	1.324*	2.652	2.408	7.056	3.228	2.306	1.646	1.353
20	1.143	1.302	1.265	1.583	1.296	2.422	2.347	6.935	3.393	2.287	1.605	1.334
21	1.147	1.323	1.284	1.887	1.257	2.347	2.321	7.258	3.521	2.273	1.593	1.309
22	1.168	1.223	1.242*	1.867	1.242	2.390	2.308	8.232	3.263	2.214	1.566	1.299
23	1.186	1.179	1.219*	1.635*	1.250	2.750	2.308	8.308	3.244	2.181	1.556	1.297
24	1.175	1.150	1.212*	1.521*	1.261	2.877	2.321	7.702	3.183	2.201	1.547	1.301
25	1.157	1.150	1.193	1.424	1.284	2.724	2.334	6.802	3.130	2.129	1.545	1.293
26	1.143	1.143	1.164	1.361	1.292	2.499	2.353	6.054	3.039	2.088	1.538	1.291
27	1.136	1.140	1.150*	1.423	1.304	2.335	2.522	5.559	3.045	2.076	1.536	1.290
28	1.126	1.154	1.150	1.970	1.388	2.256	2.575	5.312	3.016	2.026	1.479	1.283
29	1.115	1.240	1.164	3.323		2.157	2.582	5.387	2.957	2.011	1.499	1.280
30	1.126	1.246	1.172	3.855		2.031	2.525	5.322	2.858	1.998	1.471	1.601
31	1.136		1.172	2.826		1.950		5.137		2.039	1.461	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	35.812	35.826	39.115	47.511	42.247	61.064	70.940	161.242	106.451	73.099	52.158	41.662
TOTAL FLOW (cms days)	1.014	1.015	1.108	1.346	1.196	1.729	2.009	4.566	3.015	2.070	1.477	1.180
TOTAL DEPTH (in)	0.525	0.525	0.573	0.696	0.619	0.895	1.040	2.363	1.560	1.071	0.764	0.611
TOTAL DEPTH (cm)	1.333	1.334	1.456	1.769	1.573	2.273	2.641	6.003	3.963	2.721	1.942	1.551

ANNUAL SUMMARY:
Sum of Mean Daily Flow 767.127 cfs = 21.725 cms
Total Depth 11.243 in = 28.558 cm
Maximum Instantaneous Flow 8.589 cfs = 0.243 cms on May 23 at 21.00 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 11
WATERSHED AREA: 1624 ACRES (657 HECTARES)

WATER YEAR 1968
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	1.495	1.300*	1.227	1.360	1.280	2.527	2.557	2.474	2.259	1.789	1.452	1.340
2	1.802	1.292*	1.231	1.320	1.329	2.528	2.724	2.598	2.236	1.778	1.440	1.337
3	1.943	1.284*	1.253	1.283*	1.381	2.536	2.233	2.653	2.431	1.724	1.438	1.316
4	1.455	1.284*	1.280	1.282*	1.384	2.650	1.804	2.740	2.274	1.723	1.434	1.318
5	1.423	1.284*	1.324	1.273	1.480	2.996	2.663	2.833	2.241	1.727	1.440	1.302
6	1.402	1.280*	1.250	1.222*	1.590	3.219	2.575	2.783	2.303	1.697	1.426	1.287
7	1.366	1.265*	1.242	1.237*	1.651	3.049	2.551	2.664	2.320	1.691	1.417	1.272
8	1.348	1.253*	1.242	1.262	1.623	2.795	2.448	2.538	2.267	1.729	1.413	1.267
9	1.344	1.854*	1.238	1.272	1.580	2.534	2.525	2.488	2.266	1.831	1.423	1.255
10	1.333	2.476*	1.242	1.400	1.512	2.350	2.600	2.458	2.208	1.867	1.429	1.249
11	1.348	2.576*	1.257	1.275	1.480	2.216	2.846	2.448	2.212	1.781	1.423	1.250
12	1.475	1.989*	1.229*	1.269	1.441	2.150	2.845	2.566	2.173	1.819	1.413	1.280
13	1.385	1.304*	1.216	1.273	1.398	2.138	2.678	2.655	2.194	1.796	1.481	1.250
14	1.369	1.284*	1.216	1.280	1.371	2.050	2.597	2.754	2.144	1.758	1.581	1.352
15	1.344	1.280*	1.321	1.335	1.360	2.004	2.498	2.686	2.121	1.734	1.683	1.421
16	1.324	1.276*	1.984	1.372	1.340	1.987	2.385	2.582*	2.089	1.705	1.517	1.348
17	1.312	1.276*	1.926	1.312	1.344	2.013	2.278	2.504	2.070	1.709	1.543	1.304
18	1.304	1.276*	1.492	1.292	1.399	1.961	2.213	2.427	2.044	1.679	1.655	1.280
19	1.296	1.276*	1.236	1.292	1.888	1.911	2.185	2.420	2.045	1.653	1.609	1.280
20	1.284	1.276*	1.203	1.292	3.024	1.865*	2.136	2.684	2.047	1.630	1.609	1.345
21	1.348	1.288	1.223	1.292	3.667	1.789	2.101	2.628	2.001	1.618	1.571	1.394
22	1.371	1.300	1.250	1.292	3.830	1.730	2.048	2.641	2.083	1.606	1.499	1.371
23	1.345	1.288	1.310	1.292	3.847	1.785	2.036	2.556	2.060	1.593	1.468	1.324
24	1.305	1.297	1.288	1.316	3.993	1.892	2.036	2.575	1.983	1.580	1.421	1.292
25	1.300	1.273	1.400	1.340	3.678	2.063	2.036	2.639	1.997	1.572	1.394	1.273
26	1.300	1.242*	1.616	1.316*	3.276	2.125	2.036	2.611	1.976	1.564	1.389	1.257
27	1.304	1.246*	1.520	1.292*	2.898	2.101	2.036	2.497	1.962	1.520	1.386	1.242
28	1.382	1.253	1.467	1.284	2.611	2.139	2.066	2.377	1.952	1.551	1.380	1.231
29	1.324	1.256	1.440	1.273	2.508	2.315	2.185	2.350	1.974	1.555	1.373	1.231
30	1.316	1.243	1.415	1.269		2.575	2.387	2.307	1.958	1.544	1.355	1.227
31	1.308		1.381	1.265		2.575		2.279		1.480	1.346	

MONTHLY SUMMARY:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	42.955	42.077	41.918	40.133	61.164	70.567	70.308	79.415	63.889	52.004	45.407	38.894
TOTAL FLOW (cms days)	1.216	1.192	1.187	1.137	1.732	1.998	1.991	2.249	1.809	1.473	1.286	1.101
TOTAL DEPTH (in)	0.630	0.617	0.614	0.588	0.896	1.034	1.030	1.164	0.936	0.762	0.665	0.570
TOTAL DEPTH (cm)	1.599	1.566	1.560	1.494	2.277	2.627	2.617	2.956	2.378	1.936	1.690	1.448

ANNUAL SUMMARY:

Sum of Mean Daily Flow 648.731 cfs = 18.372 cms
Total Depth 9.508 in = 24.150 cm
Maximum Instantaneous Flow 4.053 cfs = 0.115 cms on February at 6.00 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 11
WATERSHED AREA: 1624 ACRES (657 HECTARES)

WATER YEAR 1969
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	1.219	1.208	1.227	1.197	1.471	1.348	4.319	3.761	3.468	2.317	1.664	1.393
2	1.216	1.208	1.223	1.204	1.445	1.398	4.704	3.650	3.396	2.266	1.662	1.375
3	1.212	1.197	1.223	1.184	1.419	1.499	5.094	3.557	3.325	2.244	1.680	1.359
4	1.208	1.227	1.231	1.203	1.389	1.569	4.701	3.556	3.256	2.218	1.664	1.354
5	1.212	1.211	1.231	1.307	1.381*	1.646	5.202	3.509	3.398	2.190	1.657	1.360
6	1.201	1.204	1.216	1.477	1.377	1.661	6.189	3.509	3.206	2.199	1.646	1.343
7	1.197	1.201	1.247	1.693	1.356	1.593	5.777	3.545	3.128	2.178	1.633	1.338
8	1.204	1.235	1.215	1.651	1.340	1.531	4.984	3.618	3.088	2.112	1.620	1.326
9	1.201	1.411	1.214	1.530	1.332	1.476	4.705	3.701	3.249	2.066	1.602	1.311
10	1.204	1.268	1.284	1.437	1.320	1.494*	4.893	3.772	3.147	2.036	1.580	1.320
11	1.252	1.340	1.349	1.389	1.324	1.480*	4.809	3.797	2.979	2.001	1.605	1.452
12	1.593	2.161	1.281	1.362	1.373	1.434*	4.838	3.924	2.911	1.969	1.563	1.467
13	1.394	1.506	1.269	2.124	1.356	1.452	5.117	4.014	2.834	1.959	1.547	1.446
14	1.276	1.336	1.269	3.347	1.322	1.496	4.930	4.072	2.784	1.981	1.533	1.380
15	1.270	1.308	1.284	2.929	1.336*	1.544	4.564	4.243	2.728	1.949	1.507	1.377
16	1.241	1.273	1.301	2.259	1.348	1.574	4.295	4.159	2.695	1.919	1.509	1.380
17	1.223	1.246	1.223	1.947	1.360	1.670	4.255	4.141	2.652	1.896	1.508	1.364
18	1.229	1.271	1.214	1.763	1.368	1.821	4.579	4.167	2.623	1.868	1.491	1.357
19	1.231	1.299	1.212	1.670	1.382	1.827	4.448	4.268	2.627	1.850	1.482	1.486
20	1.260	1.301	1.190	1.611	1.403*	1.793	4.228	4.271	2.685	1.830	1.462	1.636
21	1.243	1.311	1.157	2.647	1.451	1.869	4.149	4.112	2.599	1.812	1.458	1.493
22	1.227	1.576	1.101	2.961	1.470	2.058	4.558	4.038	2.562	1.800	1.462	1.415
23	1.223	1.437	1.178	2.480	1.474	2.060	5.132	3.993	2.630	1.789	1.480	1.387
24	1.219	1.372	1.252	2.151	1.444	1.978	5.388	3.964	2.559	1.782	1.462	1.427
25	1.212	1.332	1.258	2.019*	1.423	1.960	5.043	3.916	2.452	1.776	1.455	1.395
26	1.204	1.291	1.234	1.895*	1.385	2.106	4.636	3.851	2.423	1.754	1.458	1.372
27	1.201	1.279	1.216	1.768	1.342	2.548	4.341	3.808	2.597	1.743	1.448	1.363
28	1.201	1.262	1.198	1.666*	1.334	2.774	4.132	3.634	2.482	1.713	1.441	1.346
29	1.193	1.256	1.143*	1.590		3.187	4.016	3.613*	2.412	1.702	1.440	1.332
30	1.242	1.266	1.091*	1.520		3.638	3.864	3.673	2.364	1.693	1.434	1.359*
31	1.208		1.116*	1.493		4.087		3.546		1.682	1.416	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	38.418	39.794	37.844	56.474	38.726	59.572	141.890	119.383	85.258	60.294	47.568	41.712
TOTAL FLOW (cms days)	1.088	1.127	1.072	1.599	1.097	1.687	4.018	3.381	2.415	1.708	1.347	1.181
TOTAL DEPTH (in)	0.563	0.583	0.555	0.828	0.568	0.873	2.080	1.750	1.250	0.884	0.697	0.611
TOTAL DEPTH (cm)	1.430	1.481	1.409	2.102	1.442	2.218	5.282	4.444	3.174	2.245	1.771	1.553

ANNUAL SUMMARY:
Sum of Mean Daily Flow 766.933 cfs = 21.720 cms
Total Depth 11.240 in = 28.550 cm
Maximum Instantaneous Flow 6.576 cfs = 0.186 cms on April 6 at 14.75 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 11
WATERSHED AREA: 1624 ACRES (657 HECTARES)

WATER YEAR 1970
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	1.387	1.273	1.609*	1.150*	1.732	1.902	1.626	1.700	5.139	3.832	2.233	1.709
2	1.558	1.257	1.319	1.150*	1.611	1.902	1.617	1.835	4.939	3.607	2.209	1.699
3	1.438	1.253	1.037	1.150*	1.547	1.828	1.574	2.260	4.753	3.427	2.193	1.668
4	1.414	1.253	1.090	1.150*	1.439	1.819	1.568	3.161	4.587	3.313	2.164	2.012
5	1.394	1.328	1.147	1.150*	1.413	1.796	1.643	4.179	4.501	3.247	2.188	1.859
6	1.388	1.336	1.143	1.150*	1.436	1.775	1.936	4.903	4.490	3.248	2.143	1.794
7	1.380	1.319	1.141	1.150*	1.446	1.988	2.300	5.040	4.614	3.152	2.107	2.290
8	1.412	1.259	1.138	1.150*	1.434	2.090	2.155	4.506	4.633	3.055	2.112	2.124
9	1.480	1.242	1.136	1.150*	1.452	2.172	2.195	4.296	4.633	3.008	2.080	1.760
10	1.435	1.238	1.130	1.150*	1.525	2.233	2.678	4.206	4.570	3.003	2.058	1.710
11	1.411	1.238	1.150	1.117	1.587	2.207	2.836	3.892	4.365*	2.955	2.029	1.680
12	1.398	1.229	1.453	1.156	1.765	2.133	2.614	3.661	4.120	2.881	2.003	1.661
13	1.123	1.219	1.338	1.269	2.053	2.074	2.412	3.381	3.932	2.885	1.965	1.666
14	1.320	1.212	1.268	1.398	2.061	2.184	2.278	3.202	4.122	2.815	1.958	1.656
15	1.316	1.208	1.245	1.369	1.973	2.316	2.137	3.230	4.014	2.769	1.945	1.637
16	1.312	1.204	1.195	1.347	1.944	2.376	2.046	3.631	3.909	2.729	1.918	1.629
17	1.308	1.192	1.193	1.411	2.227	2.322	1.977	4.381	3.774*	2.683	1.885	1.617
18	1.308	1.178	1.201	1.619	2.170	2.211	1.946	5.450	3.598*	2.651	1.874	1.612
19	1.304	1.172	1.258	1.897	2.074	2.106	1.962	5.953	3.441	2.605	1.866	1.856
20	1.300	1.172	1.393	2.044	1.975	2.053	1.934	5.885	3.364	2.567	1.848	1.728
21	1.296	1.172	2.045	2.048	1.902	2.013	1.911	5.542	3.301	2.573	1.850	1.705
22	1.288	1.172	1.665	2.288	1.829	1.942	1.871	5.247	3.230	2.552	1.813	1.673
23	1.280	1.172	1.403	3.066	1.766	1.891	1.815	6.074	3.178	2.518	1.787	1.738
24	1.273	1.172	1.284	5.461	1.740	1.868	1.798	5.796	3.312	2.465	1.770	1.631
25	1.269	1.172	1.281	4.003	1.688	1.816	1.762	5.752	3.083	2.448	1.757	1.613
26	1.269	1.172	1.223	2.983	1.682	1.821	1.746	5.781	3.061	2.396	1.750	1.601
27	1.274	1.285	1.200	2.970	1.681	1.761	1.720	5.806	3.603	2.370	1.735	1.585
28	1.350	1.341	1.164*	2.785	1.699	1.764	1.706	5.749	3.658	2.248	1.723	1.571
29	1.288	1.369	1.150*	2.309		1.754	1.682	5.679	4.247	2.328	1.711	1.554
30	1.284	1.536	1.150*	2.017		1.708	1.686	5.595	4.144	2.294	1.717	1.543
31	1.284		1.150*	1.821		1.652		5.336		2.263	1.722	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	41.541	37.344	39.298	57.882	48.849	61.475	59.127	141.107	120.313	86.885	60.111	51.581
TOTAL FLOW (cms days)	1.176	1.058	1.113	1.639	1.383	1.741	1.674	3.996	3.407	2.461	1.702	1.461
TOTAL DEPTH (in)	0.609	0.547	0.576	0.848	0.716	0.901	0.867	2.068	1.763	1.273	0.881	0.756
TOTAL DEPTH (cm)	1.546	1.390	1.463	2.155	1.819	2.289	2.201	5.253	4.479	3.234	2.238	1.920

ANNUAL SUMMARY:
Sum of Mean Daily Flow 805.515 cfs = 22.812 cms
Total Depth 11.806 in = 29.987 cm
Maximum Instantaneous Flow 7.302 cfs = 0.207 cms on May 23 at 2.42 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 11
WATERSHED AREA: 1624 ACRES (657 HECTARES)

WATER YEAR 1971
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	1.530	1.408	1.553	1.231	4.009	1.950*	4.130	7.288	10.873	-----	-----	---
2	1.511	1.402	1.547	1.204	3.968	1.946*	4.002	7.981	10.098	-----	-----	-----
3	1.511	1.394	1.513	1.109	3.505	1.919	3.984	9.837*	-----	-----	-----	-----
4	1.503	1.389	1.491	1.365*	3.085	1.872	4.068	9.861*	-----	-----	-----	-----
5	1.503	1.444	1.467	1.497	2.768	1.804	4.208	9.884*	-----	-----	-----	-----
6	1.534	1.585	1.613	2.198	2.484*	1.744*	4.510	9.884*	-----	-----	-----	-----
7	1.536	1.574	1.854	1.848	2.303*	1.749	5.278	9.908*	-----	-----	-----	-----
8	1.529	1.536	2.439	1.482	2.184	1.738	5.389	9.932*	-----	-----	-----	-----
9	1.555	1.575	2.302	1.460	2.095	1.721	5.367	9.932*	-----	-----	-----	-----
10	1.621	1.582	2.045	1.461	2.107	1.698	5.635	9.956*	-----	-----	-----	-----
11	1.534	1.531	1.866	1.419	2.047	1.723	5.395	9.980*	-----	-----	-----	-----
12	1.517	1.552	1.726	1.402	2.039	2.030	4.906	9.980*	-----	-----	-----	-----
13	1.508	1.501	1.721	1.370	2.216	2.088	4.573	10.004*	-----	-----	-----	-----
14	1.484	1.439	1.710	1.369	2.474	2.071	4.759	10.028*	-----	-----	-----	-----
15	1.462	1.428	1.548	1.431	2.776	2.079	5.673	10.028*	-----	-----	-----	-----
16	1.453	1.440	1.527	1.508	2.981	2.026	5.756	10.052*	-----	-----	-----	-----
17	1.440	1.426	1.445	1.840	3.011	2.009	5.591	10.076*	-----	-----	-----	-----
18	1.435	1.397	1.361	1.872	2.925	1.941*	5.181	10.076	-----	-----	-----	-----
19	1.432	1.386	1.295	2.426	2.772	1.924*	5.033	9.886	-----	-----	-----	-----
20	1.445	1.381	1.222	4.214	2.616	1.938	5.177	9.468	-----	-----	-----	-----
21	1.453	1.357	1.308	3.796	2.472	2.006	5.723	8.528	-----	-----	-----	-----
22	1.520	1.310	1.298	2.962	2.421	2.095	5.948	8.064	-----	-----	-----	-----
23	1.543	1.366	1.086	2.565	2.367	2.263	6.095	7.884	-----	-----	-----	-----
24	1.608	2.180	1.142	2.347	2.328	2.714	6.211	7.768	-----	-----	-----	-----
25	1.498	2.160	1.242	2.182	2.256	3.208	6.004	7.617	-----	-----	-----	-----
26	1.465	1.795	1.214	2.094	2.156	4.055	5.554	7.601	-----	-----	-----	-----
27	1.409	1.667	1.223	2.023	2.110	4.836	5.356	7.954	-----	-----	-----	-----
28	1.410	1.606	1.264	1.989	2.045*	4.251	5.449	8.768	-----	-----	-----	-----
29	1.415	1.543	1.253	1.963		3.977	5.870	9.666	-----	-----	-----	-----
30	1.415	1.607	1.258	2.057		4.051	6.600	10.573	-----	-----	-----	-----
31	1.415		1.279	2.734		4.180		10.866		-----	-----	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	46.195	45.960	46.812	60.415	72.519	75.606	157.425	289.330	20.971	0.000	0.000	0.000
TOTAL FLOW (cms days)	1.308	1.302	1.326	1.711	2.054	2.141	4.458	8.194	0.594	0.000	0.000	0.000
TOTAL DEPTH (in)	0.677	0.674	0.686	0.885	1.063	1.108	2.307	4.240	0.307	0.000	0.000	0.000
TOTAL DEPTH (cm)	1.720	1.711	1.743	2.249	2.700	2.815	5.860	10.771	0.781	0.000	0.000	0.000

ANNUAL SUMMARY:
Sum of Mean Daily Flow 815.231 cfs = 23.087 cms
Total Depth 11.948 in = 30.348 cm
Maximum Instantaneous Flow 11.679 cfs = 0.331 cms on June 1 at 12.75 hours

* Indicates some data were estimated during this day.
Summaries exclude missing data.

TAILHOLT CREEK STUDY AREA
WATERSHED: 11
WATERSHED AREA: 1624 ACRES (657 HECTARES)

WATER YEAR 1975
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	-----	-----	-----	-----	-----	-----	-----	-----	-----	3.871	2.589	2.011
2	-----	-----	-----	-----	-----	-----	-----	-----	-----	3.787	2.591	2.014
3	-----	-----	-----	-----	-----	-----	-----	-----	-----	3.702	2.596	2.011
4	-----	-----	-----	-----	-----	-----	-----	-----	-----	3.633	2.593	1.973
5	-----	-----	-----	-----	-----	-----	-----	-----	-----	3.593	2.570	1.945
6	-----	-----	-----	-----	-----	-----	-----	-----	-----	3.544	2.549	1.932
7	-----	-----	-----	-----	-----	-----	-----	-----	-----	3.521	2.421	1.901
8	-----	-----	-----	-----	-----	-----	-----	-----	-----	3.442	2.350	1.879
9	-----	-----	-----	-----	-----	-----	-----	-----	-----	3.372	2.352	1.878
10	-----	-----	-----	-----	-----	-----	-----	-----	-----	3.381	2.333	1.856
11	-----	-----	-----	-----	-----	-----	-----	-----	-----	3.314	2.329	1.864
12	-----	-----	-----	-----	-----	-----	-----	-----	-----	3.365	2.353	1.850
13	-----	-----	-----	-----	-----	-----	-----	-----	-----	3.386	2.370	1.844
14	-----	-----	-----	-----	-----	-----	-----	-----	-----	3.265	2.372	1.830
15	-----	-----	-----	-----	-----	-----	-----	-----	-----	3.170	2.347	1.801
16	-----	-----	-----	-----	-----	-----	-----	-----	-----	3.123	2.387	1.763
17	-----	-----	-----	-----	-----	-----	-----	-----	-----	3.115	2.380	1.741
18	-----	-----	-----	-----	-----	-----	-----	-----	4.847	3.123	2.379	1.731
19	-----	-----	-----	-----	-----	-----	-----	-----	5.020	3.112	2.374	1.724
20	-----	-----	-----	-----	-----	-----	-----	-----	4.914	3.013	2.372	1.721
21	-----	-----	-----	-----	-----	-----	-----	-----	4.738	2.958	2.386	1.717
22	-----	-----	-----	-----	-----	-----	-----	-----	4.667	2.944	2.396	1.715
23	-----	-----	-----	-----	-----	-----	-----	-----	4.474	2.899	2.387	1.698
24	-----	-----	-----	-----	-----	-----	-----	-----	4.330	2.831	2.361	1.685
25	-----	-----	-----	-----	-----	-----	-----	-----	4.451	2.802	2.363	1.654
26	-----	-----	-----	-----	-----	-----	-----	-----	4.537	2.762	2.183	1.651
27	-----	-----	-----	-----	-----	-----	-----	-----	4.319	2.720	2.021	1.650
28	-----	-----	-----	-----	-----	-----	-----	-----	4.254	2.678	2.039	1.634
29	-----	-----	-----	-----		-----	-----	-----	4.102	2.678	2.060	1.612
30	-----	-----	-----	-----		-----	-----	-----	3.972	2.598	2.012	1.600
31	-----		-----	-----		-----		-----		2.564	2.006	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	58.625	98.265	72.819	53.883
TOTAL FLOW (cms days)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.660	2.783	2.062	1.526
TOTAL DEPTH (in)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.859	1.440	1.067	0.790
TOTAL DEPTH (cm)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	2.182	3.658	2.711	2.006

ANNUAL SUMMARY:
Sum of Mean Daily Flow 283.593 cfs = 8.031 cms
Total Depth 4.156 in = 10.557 cm
Maximum Instantaneous Flow 5.126 cfs = 0.145 cms on June 19 at 21.00 hours

* Indicates some data were estimated during this day.
Summaries exclude missing data.

TAILHOLT CREEK STUDY AREA
WATERSHED: 11
WATERSHED AREA: 1624 ACRES (657 HECTARES)

WATER YEAR 1976
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	1.565	1.724	1.565	1.582	1.670	1.835	2.525	1.516	5.489	3.216	2.322	1.835
2	1.614	1.728	1.564	1.563	1.692	7.441	2.520	1.842	5.345	3.172	2.321	1.826
3	1.591	1.771	1.559	1.540	1.701	10.880	2.564	2.413	5.239	3.138	2.295	1.803
4	1.559	1.742	1.557	1.538	1.672	2.515	2.911	3.477	5.111	3.108	2.264	1.792
5	1.536	1.701	1.562	1.549	1.723	1.672	3.618	3.497	5.004	2.993	2.239	1.776
6	2.052	1.681	1.566	1.552	1.481	1.620	4.256	3.561	4.844	2.945	2.218	1.732
7	2.004	1.713	1.561	1.538	1.471	1.653	5.083	3.756	4.770	2.914	2.203	1.731
8	1.576	1.672	1.557	1.538	1.564	1.689	6.633	4.415	4.690	2.878	2.189	1.718
9	1.541	1.640	1.557	1.538	1.593	1.795	10.043	5.278	4.614	2.843	2.187	1.702
10	1.509	1.631	1.557	1.515	1.575	2.162	10.068	6.522	4.814	2.798	2.186	1.726
11	1.616	1.608	1.566	1.511	1.574	2.323	9.091	9.095	5.015	2.770	2.181	1.728
12	1.611	1.599	1.559	1.511	1.574	2.238	9.092	9.062	4.839	2.899	2.163	1.721
13	1.582	1.581	1.586	1.500	1.559	2.192	9.109	9.372	5.172	2.745	2.094	1.721
14	1.557	1.573	1.637	1.504	1.573	2.092	8.684	9.485	4.691	2.663	2.085	1.717
15	1.538	1.906	1.687	1.655	1.562	2.005	8.027	8.968	4.552	2.624	2.061	1.706
16	1.531	2.128	1.734	1.668	1.559	1.978	6.993	8.709	4.452	2.584	2.059	1.698
17	1.515	1.883	1.791	1.656	1.543	2.002	6.359	8.518	4.349	2.633	2.012	1.693
18	1.510	1.751	3.309	1.671	1.538	2.229	5.967	8.255	4.204	3.383	2.000	1.687
19	1.502	1.728	4.156	1.663	1.525	2.256	5.408	7.997	4.059	2.909	1.978	1.687
20	1.485	1.697	2.586	1.694	1.505	2.239	5.216	7.780	4.110	2.639	1.958	1.684
21	1.921	1.676	1.842	1.717	1.482	2.199	5.086	7.539	4.206	2.592	1.940	1.681
22	1.721	1.654	1.707	1.665	1.484	2.259	4.746	7.356	4.005	2.549	1.926	2.049
23	1.572	1.632	1.682	1.661	1.484	2.262	4.169	7.189	3.862	2.523	1.925	2.030
24	1.552	1.632	1.686	1.626	1.494	2.409	3.646	6.837	3.773	2.622	1.919	1.939
25	1.560	1.587	1.682	1.603	1.502	2.346	3.209	6.700	3.639	2.537	1.915	1.885
26	1.877	1.575	1.719	1.603	1.671	2.299	2.825	6.447	3.555	2.478	1.917	1.828
27	1.711	1.575	1.701	1.603	1.785	2.270	2.399	6.247	3.477	2.423	1.903	1.798
28	1.644	1.575	1.741	1.601	1.867	2.194	1.951	6.293	3.390	2.386	1.874	1.772
29	1.622	1.575	1.635	1.598	1.876	2.124	1.578	5.862	3.329	2.370	1.845	1.740
30	1.673	1.567	1.650	1.605		2.172	1.398	5.739	3.267	2.339	1.866	1.717
31	1.663		1.601	1.636		2.381		5.815		2.330	1.853	

MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	50.510	50.507	55.857	49.405	46.299	79.732	155.176	195.542	131.869	85.004	63.899	53.123
TOTAL FLOW (cms days)	1.430	1.430	1.582	1.399	1.311	2.258	4.395	5.538	3.735	2.407	1.810	1.504
TOTAL DEPTH (in)	0.740	0.740	0.819	0.724	0.679	1.169	2.274	2.866	1.933	1.246	0.937	0.779
TOTAL DEPTH (cm)	1.880	1.880	2.079	1.839	1.724	2.968	5.777	7.279	4.909	3.164	2.379	1.978

ANNUAL SUMMARY:
Sum of Mean Daily Flow 1016.922 cfs = 28.799 cms
Total Depth 14.904 in = 37.857 cm
Maximum Instantaneous Flow 29.258 cfs = 0.829 cms on March 3 at 18.00 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 11
WATERSHED AREA: 1624 ACRES (657 HECTARES)

WATER YEAR 1977
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	1.613	1.398	1.707	1.081	1.308	1.300	1.236	1.239	1.146	0.970	0.906	1.012
2	1.674	1.398	1.611	1.018	1.300	1.303	1.234	1.279	1.129	0.977	0.912	0.985
3	1.672	1.398	1.538	1.228	1.300	1.310	1.232	1.242	1.117	1.536	0.927	0.958
4	1.642	1.476	1.516	1.284	1.303	1.315	1.243	1.239	1.101	1.065	0.911	0.950
5	1.622	1.475	1.496	1.284	1.300	1.316	1.290	1.222	1.078	1.016	0.908	0.937
6	1.613	1.466	1.446	1.283	1.300	1.313	1.383	1.224	1.072	0.987	0.990	0.929
7	1.598	1.459	1.437	1.281	1.300	1.319	1.565	1.237	1.086	0.972	0.938	0.922
8	1.582	1.453	1.660	1.283	1.303	1.315	1.814	1.235	1.230	0.958	0.942	0.911
9	1.571	1.458	1.759	1.281	1.303	1.346	1.782	1.226	1.192	0.964	0.936	0.906
10	1.566	1.450	1.709	1.281	1.307	1.344	1.610	1.223	1.168	0.954	0.928	0.905
11	1.560	1.438	1.656	1.277	1.313	1.365	1.534	1.208	1.231	0.935	0.926	0.904
12	1.541	1.426	1.598	1.282	1.308	1.354	1.495	1.187	1.181	0.926	0.919	0.908
13	1.532	1.423	1.545	1.289	1.306	1.343	1.466	1.173	1.134	0.923	0.912	0.908
14	1.523	1.419	1.510	1.291	1.300	1.332	1.441	1.162	1.126	0.918	0.920	0.907
15	1.509	1.418	1.343	1.292	1.298	1.520	1.400	1.168	1.102	0.912	0.928	1.020
16	1.496	1.421	1.340	1.292	1.301	1.408	1.390	1.228	1.082	0.903	0.912	1.120
17	1.485	1.423	1.340	1.295	1.300	1.366	1.377	1.266	1.063	0.901	0.906	1.208
18	1.467	1.419	1.340	1.299	1.301	1.335	1.362	1.295	1.048	0.914	0.909	1.105
19	1.454	1.421	1.349	1.293	1.305	1.323	1.337	1.298	1.056	0.982	0.902	1.038
20	1.442	1.420	1.362	1.295	1.308	1.299	1.303	1.235	1.094	0.932	0.895	1.053
21	1.429	1.403	1.398	1.296	1.308	1.300	1.294	1.204	1.071	0.933	0.901	1.091
22	1.423	1.398	1.396	1.296	1.309	1.304	1.293	1.174	1.027	0.945	0.931	1.087
23	1.423	1.398	1.318	1.293	1.308	1.325	1.292	1.215	1.012	0.938	0.914	1.080
24	1.423	1.393	1.297	1.292	1.305	1.332	1.293	1.263	1.000	1.083	0.932	1.164
25	1.423	1.396	1.293	1.292	1.308	1.304	1.296	1.280	0.996	1.303	1.035	1.181
26	1.424	1.387	1.303	1.285	1.303	1.278	1.289	1.217	0.988	0.966	1.075	1.143
27	1.423	1.606	1.298	1.291	1.305	1.278	1.272	1.283	0.977	0.948	1.062	1.076
28	1.423	2.057	1.277	1.292	1.307	1.287	1.248	1.244	0.978	0.932	1.000	1.045
29	1.423	2.057	1.276	1.298		1.253	1.216	1.219	0.980	0.922	0.997	1.232
30	1.412	1.841	1.270	1.298		1.237	1.201	1.193	0.971	0.920	1.076	1.208
31	1.404		1.222	1.300		1.233		1.177		0.913	1.037	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	46.793	44.595	44.610	39.443	36.516	40.956	41.189	38.055	32.438	30.449	29.387	30.891
TOTAL FLOW (cms days)	1.325	1.263	1.263	1.117	1.034	1.160	1.166	1.078	0.919	0.862	0.832	0.875
TOTAL DEPTH (in)	0.686	0.654	0.654	0.578	0.535	0.600	0.604	0.558	0.475	0.446	0.431	0.453
TOTAL DEPTH (cm)	1.742	1.660	1.661	1.468	1.359	1.525	1.533	1.417	1.208	1.134	1.094	1.150

ANNUAL SUMMARY:
Sum of Mean Daily Flow 455.322 cfs = 12.895 cms
Total Depth 6.673 in = 16.950 cm
Maximum Instantaneous Flow 2.837 cfs = 0.080 cms on July 3 at 12.00 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 11
WATERSHED AREA: 1624 ACRES (657 HECTARES)

WATER YEAR 1978
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	1.067	1.086	1.124	1.170	1.300	1.949	6.964	4.743	4.001	3.228	2.228	1.792
2	1.066	1.090	1.405	1.163	1.304	1.981	6.037	4.711	3.929	3.190	2.196	1.770
3	1.039	1.082	1.554	1.150	1.307	2.026	4.948	4.615	3.872	3.398	2.181	1.745
4	1.032	1.069	1.414	1.144	1.316	2.049	4.407	4.522	3.809	3.400	2.160	1.742
5	1.022	1.081	1.300	1.197	1.328	2.075	3.942	4.394	3.757	3.320	2.183	1.772
6	1.022	1.109	1.253	1.197	1.457	2.094	3.878	4.237	3.716	3.155	2.148	1.901
7	1.090	1.095	1.229	1.162	1.608	2.180	3.832	4.096	3.668	3.039	2.088	2.036
8	1.069	1.072	1.171	1.147	1.775	2.319	3.710	3.965	3.637	3.173	2.064	1.847
9	1.054	1.055	1.150	1.179	1.834	2.550	3.599	3.916	3.643	3.017	2.042	1.771
10	1.046	1.052	1.150	1.184	1.813	2.866	3.594	4.199	4.050	2.886	2.044	1.817
11	1.036	1.067	1.267	1.180	1.733	2.879	3.691	4.078	3.974	2.806	2.016	1.838
12	1.039	1.063	1.325	1.185	1.626	2.743	3.688	4.012	3.900	2.748	1.997	1.805
13	1.042	1.062	1.543	1.195	1.547	2.479	3.651	4.106	3.906	2.708	2.266	1.785
14	1.048	1.076	3.117	1.197	1.522	2.294	3.573	4.081	3.930	2.662	2.191	1.744
15	1.052	1.089	7.102	1.212	1.517	2.147	3.588	4.214	3.923	2.630	2.085	1.684
16	1.041	1.111	4.610	1.225	1.492	2.033	3.644	4.233	3.933	2.596	2.177	1.670
17	1.046	1.076	2.614	1.282	1.412	2.048	3.526	4.277	3.899	2.562	2.118	1.674
18	1.047	1.066	2.005	1.329	1.413	2.310	3.362	4.316	3.907	2.550	2.053	1.717
19	1.042	1.125	1.717	1.413	1.398	2.763	3.308	4.284	3.953	2.543	1.982	1.708
20	1.037	1.150	1.562	1.432	1.369	2.950	3.383	4.256	3.867	2.513	1.951	1.668
21	1.036	1.150	1.524	1.439	1.376	3.308	3.340	4.219	3.681	2.490	1.931	1.652
22	1.035	1.150	1.441	1.433	1.455	3.735	3.266	4.213	3.599	2.465	2.017	1.640
23	1.035	1.131	1.366	1.433	1.591	4.037	3.262	4.304	3.558	2.435	1.997	1.609
24	1.028	1.065	1.355	1.432	1.702	4.087	3.213	4.431	3.520	2.416	1.911	1.599
25	1.128	1.147	1.300	1.448	1.775	3.825	3.232	4.409	3.792	2.378	1.877	1.593
26	1.273	1.285	1.263	1.439	1.903	3.924	3.598	4.350	3.608	2.354	1.879	1.579
27	1.119	1.151	1.234	1.363	1.995	4.504	4.272	4.294	3.461	2.328	1.856	1.559
28	1.091	1.137	1.212	1.309	1.947	5.277	4.349	4.220	3.382	2.413	1.845	1.542
29	1.086	1.143	1.202	1.307		5.894	4.448	4.182	3.284	2.359	1.824	1.547
30	1.084	1.136	1.185	1.302		6.605	4.541	4.122	3.234	2.291	1.826	1.543
31	1.084		1.174	1.304		6.710		4.060		2.255	1.817	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	32.936	33.169	53.867	39.553	43.816	98.641	117.842	132.059	112.394	84.307	62.953	51.350
TOTAL FLOW (cms days)	0.933	0.939	1.526	1.120	1.241	2.794	3.337	3.740	3.183	2.388	1.783	1.454
TOTAL DEPTH (in)	0.483	0.486	0.789	0.580	0.642	1.446	1.727	1.935	1.647	1.236	0.923	0.753
TOTAL DEPTH (cm)	1.226	1.235	2.005	1.472	1.631	3.672	4.387	4.916	4.184	3.138	2.344	1.912

ANNUAL SUMMARY:
Sum of Mean Daily Flow 862.888 cfs = 24.437 cms
Total Depth 12.647 in = 32.122 cm
Maximum Instantaneous Flow 7.826 cfs = 0.222 cms on December 15 at 17.00 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 11
WATERSHED AREA: 1624 ACRES (657 HECTARES)

WATER YEAR 1979
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	1.486	1.390	1.373	1.373	1.373	1.373	1.775	2.755	1.852	1.560	1.330	1.287
2	1.537	1.397	1.373	1.373	1.373	1.373	1.775	2.754	1.815	1.551	1.327	1.241
3	1.513	1.392	1.373	1.373	1.373	1.371	1.782	2.682	1.781	1.614	1.313	1.223
4	1.487	1.389	1.373	1.373	1.373	1.371	1.782	2.651	1.742	1.584	1.312	1.231
5	1.465	1.380	1.373	1.373	1.373	1.480	1.782	2.656	1.741	1.551	1.305	1.216
6	1.458	1.373	1.373	1.373	1.373	1.679	1.782	2.636	1.809	1.540	1.300	1.183
7	1.441	1.405	1.373	1.373	1.373	1.782	1.782	2.492	1.833	1.526	1.304	1.153
8	1.419	1.410	1.373	1.373	1.370	1.782	1.782	2.425	1.668	1.479	1.280	1.132
9	1.403	1.373	1.373	1.373	1.373	1.777	1.782	2.321	1.667	1.455	1.262	1.133
10	1.380	1.373	1.373	1.373	1.367	1.781	1.782	2.212	1.658	1.454	1.251	1.132
11	1.357	1.373	1.373	1.373	1.373	1.782	1.780	2.124	1.641	1.464	1.247	1.131
12	1.351	1.373	1.373	1.373	1.373	1.782	1.782	2.058	1.605	1.461	1.298	1.127
13	1.384	1.373	1.373	1.373	1.373	1.782	1.773	2.029	1.607	1.444	1.408	1.117
14	1.385	1.373	1.373	1.373	1.373	1.782	1.772	2.025	1.603	1.445	1.385	1.107
15	1.390	1.373	1.373	1.373	1.373	1.782	1.782	2.016	1.599	1.440	1.306	1.102
16	1.388	1.373	1.373	1.373	1.373	1.782	1.782	2.009	1.600	1.426	1.291	1.094
17	1.382	1.373	1.373	1.373	1.373	1.782	1.782	2.014	1.720	1.411	1.291	1.100
18	1.385	1.373	1.373	1.373	1.373	1.782	1.782	2.017	2.170	1.399	1.301	1.088
19	1.396	1.373	1.373	1.373	1.372	1.782	1.782	2.030	1.761	1.395	1.297	1.091
20	1.397	1.373	1.373	1.373	1.371	1.782	1.767	2.047	1.691	1.390	1.280	1.087
21	1.395	1.373	1.373	1.373	1.373	1.782	1.793	2.037	1.678	1.413	1.257	1.086
22	1.397	1.373	1.373	1.373	1.367	1.782	1.838	2.028	1.660	1.653	1.249	1.088
23	1.393	1.373	1.373	1.373	1.373	1.782	2.098	2.015	1.637	1.476	1.279	1.089
24	1.398	1.373	1.373	1.373	1.373	1.782	2.123	2.013	1.624	1.411	1.316	1.087
25	1.405	1.373	1.373	1.373	1.373	1.782	2.097	1.999	1.601	1.385	1.261	1.103
26	1.402	1.373	1.373	1.373	1.373	1.782	2.135	1.937	1.596	1.376	1.251	1.135
27	1.399	1.373	1.373	1.373	1.373	1.782	2.325	1.929	1.578	1.371	1.276	1.108
28	1.394	1.373	1.373	1.373	1.373	1.782	2.550	1.941	1.577	1.387	1.269	1.101
29	1.385	1.373	1.373	1.373		1.782	2.704	1.957	1.574	1.374	1.280	1.099
30	1.390	1.373	1.373	1.373		1.782	2.769	1.933	1.578	1.358	1.311	1.112
31	1.382		1.373	1.373		1.782		1.891		1.343	1.351	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	43.745	41.337	42.556	42.556	38.419	53.196	58.026	67.633	50.663	45.137	40.184	33.982
TOTAL FLOW (cms days)	1.239	1.171	1.205	1.205	1.088	1.506	1.643	1.915	1.435	1.278	1.138	0.962
TOTAL DEPTH (in)	0.641	0.606	0.624	0.624	0.563	0.780	0.850	0.991	0.743	0.662	0.589	0.498
TOTAL DEPTH (cm)	1.628	1.539	1.584	1.584	1.430	1.980	2.160	2.518	1.886	1.680	1.496	1.265

ANNUAL SUMMARY:
Sum of Mean Daily Flow 557.434 cfs = 15.787 cms
Total Depth 8.170 in = 20.751 cm
Maximum Instantaneous Flow 3.289 cfs = 0.093 cms on June 18 at 7.00 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 11
WATERSHED AREA: 1624 ACRES (657 HECTARES)

WATER YEAR 1980
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	1.042	1.136	1.217	1.110	1.294	1.688	1.351	4.205	3.212	2.499	1.797	1.754
2	1.090	1.132	1.241	1.106	1.297	1.675	1.340	4.013	3.594	2.767	1.769	1.731
3	1.089	1.122	1.267	1.101	1.271	1.628	1.338	3.902	3.553	3.023	1.753	1.601
4	1.087	1.138	1.289	1.102	1.169	1.606	1.337	3.805	3.517	2.643	1.741	1.515
5	1.080	1.154	1.266	1.101	1.137	1.604	1.484	3.726	3.460	2.544	1.729	1.493
6	1.080	1.160	1.227	1.113	1.121	1.575	1.557	3.693	3.409	2.460	1.723	1.472
7	1.079	1.160	1.224	1.114	1.086	1.507	1.518	3.593	3.333	2.400	1.707	1.477
8	1.081	1.155	1.224	1.121	1.070	1.454	1.540	3.557	3.241	2.350	1.690	1.465
9	1.084	1.130	1.216	1.123	1.063	1.400	1.876	3.543	3.144	2.304	1.674	1.454
10	1.078	1.123	1.215	1.132	1.060	1.385	2.076	3.450	3.067	2.258	1.672	1.733
11	1.079	1.123	1.218	1.142	1.059	1.438	2.163	3.323	3.020	2.248	1.689	1.654
12	1.081	1.121	1.209	1.388	1.064	1.400	2.223	3.213	3.056	2.238	1.690	1.558
13	1.084	1.115	1.195	1.809	1.073	1.400	2.449	3.129	3.031	2.221	1.694	1.796
14	1.086	1.119	1.194	2.207	1.077	1.719	2.778	3.040	3.257	2.224	1.698	1.623
15	1.283	1.117	1.195	2.208	1.078	1.825	3.019	3.134	3.093	2.224	1.704	1.537
16	1.154	1.119	1.193	1.767	1.078	1.721	3.058	3.090	2.967	2.166	1.709	1.477
17	1.153	1.171	1.194	1.552	1.096	1.631	3.310	2.935	2.876	2.133	1.698	1.453
18	1.177	1.160	1.193	1.406	1.389	1.598	3.936	2.837	2.834	2.110	1.797	1.742
19	1.367	1.127	1.189	1.361	1.714	1.527	4.355	2.770	2.791	2.087	1.806	1.613
20	1.191	1.103	1.189	1.353	1.860	1.517	4.882	2.717	2.768	2.064	1.769	1.562
21	1.182	1.105	1.191	1.341	1.867	1.571	5.214	2.668	2.742	2.058	1.745	1.546
22	1.184	1.116	1.190	1.325	1.671	1.592	5.218	2.706	2.737	2.033	1.729	1.503
23	1.286	1.121	1.159	1.316	1.544	1.612	5.271	2.961	2.814	1.990	1.733	1.477
24	1.183	1.126	1.189	1.306	1.446	1.589	5.564	2.836	2.721	1.970	1.728	1.473
25	1.236	1.135	1.203	1.293	1.418	1.554	5.457	2.973	2.600	1.958	1.721	1.455
26	1.319	1.144	1.183	1.292	1.456	1.509	5.005	3.098	2.565	1.930	1.719	1.440
27	1.172	1.152	1.152	1.288	1.601	1.472	4.736	3.032	2.564	1.901	1.728	1.429
28	1.169	1.179	1.143	1.298	1.826	1.414	4.707	3.001	2.534	1.887	1.738	1.410
29	1.159	1.192	1.128	1.295	1.770	1.410	4.716	3.076	2.514	1.849	1.740	1.399
30	1.150	1.202	1.124	1.296		1.376	4.472	3.096	2.514	1.822	1.733	1.379*
31	1.141		1.119	1.294		1.356		3.114		1.810	1.747	

MONTHLY SUMMARY:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	35.625	34.158	37.136	41.661	38.657	47.755	97.950	100.234	89.530	68.173	53.568	46.222
TOTAL FLOW (cms days)	1.009	0.967	1.052	1.180	1.095	1.352	2.774	2.839	2.535	1.931	1.517	1.309
TOTAL DEPTH (in)	0.522	0.501	0.544	0.611	0.567	0.700	1.436	1.469	1.312	0.999	0.785	0.677
TOTAL DEPTH (cm)	1.326	1.272	1.382	1.551	1.439	1.778	3.646	3.731	3.333	2.538	1.994	1.721

ANNUAL SUMMARY:

Sum of Mean Daily Flow 690.669 cfs = 19.560 cms
Total Depth 10.123 in = 25.711 cm
Maximum Instantaneous Flow 5.854 cfs = 0.166 cms on April 24 at 21.57 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 11
WATERSHED AREA: 1624 ACRES (657 HECTARES)

WATER YEAR 1981
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	1.368	1.292	1.254	1.990	1.270	1.839	2.114	2.985	2.932	3.003	2.081	1.608
2	1.368	1.289	1.523	1.862	1.270	1.788	2.116	2.968	2.861	2.987	2.057	1.602
3	1.368	1.282	2.314	1.754	1.577	1.751	2.134	2.906	2.819	2.909	2.047	1.588
4	1.358	1.284	3.247	1.665	1.577	1.726	2.122	2.884	2.768	2.843	2.030	1.578
5	1.352	1.284	2.319	1.597	1.521	1.713	2.121	2.849	2.731	2.805	2.014	1.561
6	1.351	1.355	1.800	1.528	1.385	1.672	2.087	2.788	2.943	2.913	1.986	1.539
7	1.349	1.930	1.589	1.477	1.235*	1.630	2.055	2.748	2.927	2.974	1.955	1.520
8	1.341	1.512	1.486	1.433	1.228*	1.605	2.015	2.715	3.282	2.827	1.930	1.494
9	1.338	1.418	1.438	1.405	1.214*	1.579	2.021	2.648	3.677	2.745	1.918	1.479
10	1.336	1.429	1.397	1.351	1.212*	1.559	1.947	2.692	3.739	2.683	1.915	1.478
11	1.333	1.388	1.355	1.324	1.220*	1.548	1.917	2.668	3.694	2.657	1.892	1.489
12	1.399	1.381	1.328	1.295	1.224	1.591	1.880	2.621	3.692	2.630	1.862	1.478
13	1.411	1.331	1.290	1.275	1.252	1.635	1.828	2.572	3.794	2.592	1.844	1.469
14	1.360	1.296	1.273	1.264	1.500	1.655	1.811	2.762	3.819	2.552	1.826	1.461
15	1.368	1.280	1.306	1.256	1.313	1.665	1.853	2.995	3.855	2.522	1.806	1.456
16	1.365	1.275	1.342	1.268	1.880	1.753	1.915	2.929	3.860	2.480	1.778	1.441
17	1.350	1.276	1.356	1.296	2.142	1.732	1.942	2.863	3.881	2.438	1.764	1.422
18	1.346	1.276	1.343	1.306	2.100	1.713	2.009	2.801	3.812	2.414	1.770	1.406
19	1.342	1.270	1.326	1.302	3.127	1.721	2.130	2.789	3.922	2.389	1.785	1.422
20	1.341	1.262	1.312	1.296	3.702	1.724	2.288	2.944	4.060	2.351	1.787	1.425
21	1.327	1.277	1.435	1.290	3.159	1.712	2.399	3.205	4.071	2.327	1.744	1.414
22	1.315	1.310	2.040	1.283	2.760	1.782	2.385	3.255	4.021	2.298	1.722	1.414
23	1.314	1.262	1.992	1.396	2.504	1.747	2.396	3.290	3.894	2.281	1.694	1.416
24	1.315	1.250	1.869	1.397	2.342	1.710	2.423	3.272	3.699	2.265	1.671	1.411
25	1.412	1.240	2.389	1.319	2.201	1.758	2.514	3.339	3.588	2.255	1.649	1.483
26	1.455	1.245	4.227	1.291	2.093	1.925	2.742	3.293	3.521	2.251	1.636	1.488
27	1.363	1.245	4.402	1.289	1.988	1.897	3.224	3.126	3.377	2.221	1.637	1.538
28	1.321	1.253	3.492	1.320	1.902	1.875	3.105	3.024	3.276	2.194	1.640	1.894
29	1.308	1.272	2.762	1.306		1.943	3.071	3.019	3.211	2.169	1.624	1.470
30	1.304	1.278	2.403	1.293		1.930	3.024	3.073	3.092	2.130	1.634	1.440
31	1.299		2.153	1.286		1.939		3.105		2.114	1.629	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	41.875	39.744	60.762	43.411	51.897	53.819	67.590	91.130	104.816	78.221	56.327	44.884
TOTAL FLOW (cms days)	1.186	1.126	1.721	1.229	1.470	1.524	1.914	2.581	2.968	2.215	1.595	1.271
TOTAL DEPTH (in)	0.614	0.582	0.891	0.636	0.761	0.789	0.991	1.336	1.536	1.146	0.826	0.658
TOTAL DEPTH (cm)	1.559	1.480	2.262	1.616	1.932	2.004	2.516	3.392	3.902	2.912	2.097	1.671

ANNUAL SUMMARY:
Sum of Mean Daily Flow 734.474 cfs = 20.800 cms
Total Depth 10.765 in = 27.342 cm
Maximum Instantaneous Flow 4.825 cfs = 0.137 cms on December 26 at 20.99 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 11
WATERSHED AREA: 1624 ACRES (657 HECTARES)

WATER YEAR 1982
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	1.404	1.374	1.394	1.702	1.392	3.619	1.944	7.423	6.951	5.392	3.204	2.051
2	1.401	1.368	1.475	1.636	1.392	3.112	1.922	8.030	6.680	5.268	3.188	2.040
3	1.490	1.356	1.417	1.612	1.392	2.690	1.909	9.668	6.545	5.174	3.139	2.025
4	1.444	1.350	1.407	1.610	1.389*	2.375*	1.897	9.896	6.809	5.121	3.082	2.002
5	1.425	1.349	1.479	1.565	1.385*	2.407	1.881	9.739	7.264	4.974	3.035	1.984
6	1.412	1.346	2.394	1.535*	1.374	2.293	1.861	9.606	7.533	4.867	2.977	1.960
7	1.477	1.345	2.942	1.514*	1.347	2.186	1.846	9.458	7.651	5.044	2.932	1.942
8	1.466	1.344	2.489	1.490	1.286	2.144	1.832	9.363	7.598	4.868	2.947	1.925
9	1.448	1.338	2.303	1.474	1.295	2.065	1.827*	9.319	7.557	4.683	2.946	1.917
10	1.545	1.330	3.155	1.464	1.266	2.026	2.007*	9.241	7.354	4.549	2.862	1.985
11	1.683	1.328	2.722	1.461	1.273	2.112	4.162*	9.128	7.058	4.456	2.839	1.963
12	1.534	1.475	2.314	1.460	1.278	2.303	6.942*	9.134	6.821	4.344	2.815	2.103
13	1.457	1.499	2.068	1.458	1.322	2.336	8.853*	9.197	6.722	4.235	2.757	2.011
14	1.433	1.650	1.935	1.445	1.858	2.210	7.407	9.329	6.668	4.162	2.714	1.944
15	1.401	1.545	1.969	1.439	2.172	2.438	6.237	9.815	6.659	4.059	2.670	1.931
16	1.396	1.962	1.941	1.436	4.293	2.379	5.385	10.351	6.749	3.938	2.632	1.924
17	1.387	2.050	1.907	1.436	5.225	2.361	4.817	10.744*	6.930	3.854	2.571	1.895
18	1.371	1.810	1.902	1.438	4.993	2.308	4.431	9.534*	6.912	3.778	2.576	1.884
19	1.365	1.593	2.722	1.430	4.944	2.236	4.151	7.971*	6.865	3.701	2.552	1.957
20	1.366	1.510	5.779	1.407*	7.119	2.186	3.962	6.649*	6.681	3.651	2.550	2.134
21	1.368	1.586	4.795	1.392	14.873	2.062	3.895	6.104*	6.550	3.571	2.514	1.949
22	1.364	2.010	3.617	1.379	44.820	1.996	3.911	6.283*	6.450	3.527	2.480	1.902
23	1.364	1.824	2.915	1.382	22.683	1.966	4.151	6.483*	6.412	3.500	2.254	1.880
24	1.363	1.687	2.583	1.412	12.573	1.949	4.901	6.648*	6.527	3.474	2.210	1.896
25	1.363	1.565	2.374	1.394	8.401	1.907	5.664	6.557	6.679	3.446	2.179	1.970
26	1.479	1.508	2.185	1.444	6.410	1.895	6.109	9.196*	6.519	3.417	2.142	2.326
27	1.393	1.477	2.054	1.426	5.261	1.892	6.405	7.325*	6.302	3.380	2.130	2.096
28	1.391	1.436	1.953	1.404	4.324	1.912	6.920	6.693*	6.336	3.352	2.101	2.036
29	1.401	1.417	1.863	1.392		1.952	7.189	7.356*	5.435	3.302	2.119	2.156
30	1.380	1.409	1.795	1.393		1.955	7.309	8.216*	5.226	3.254	2.129	1.935
31	1.374		1.816	1.394		1.951		7.246		3.221	2.080	

MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	44.144	45.844	73.663	45.424	167.339	69.221	131.729	261.706	202.441	127.563	81.324	59.723
TOTAL FLOW (cms days)	1.250	1.298	2.086	1.286	4.739	1.960	3.731	7.412	5.733	3.613	2.303	1.691
TOTAL DEPTH (in)	0.647	0.672	1.080	0.666	2.453	1.015	1.931	3.836	2.967	1.870	1.192	0.875
TOTAL DEPTH (cm)	1.643	1.707	2.742	1.691	6.229	2.577	4.904	9.742	7.536	4.749	3.027	2.223

ANNUAL SUMMARY:
Sum of Mean Daily Flow 1310.122 cfs = 37.103 cms
Total Depth 19.201 in = 48.772 cm
Maximum Instantaneous Flow 53.176 cfs = 1.506 cms on February 22 at 9.10 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 12
WATERSHED AREA: 931 ACRES (376 HECTARES)

WATER YEAR 1963
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.321	0.406	0.876*	0.563	0.847	0.909	1.876	1.346	0.859	1.015	0.438	0.419
2	0.321	0.399	1.264*	0.558	0.569	0.909	1.845	1.354	0.825	0.938	0.437	0.393
3	0.321	0.392	2.046*	0.552	1.357	0.906	1.815	1.678	0.832	0.888	0.432	0.366
4	0.321	0.385	1.783*	0.546	1.638	0.898	1.756	1.596	1.025	0.846	0.432	0.353
5	0.321	0.517	1.540	0.520	2.064	0.894	1.733	1.608	1.629	0.805	0.425	0.328
6	0.321	0.459	1.429	0.495	2.199	0.839	2.343	1.608	1.128	0.784	0.425	0.324
7	0.327	0.410	1.304	0.494	2.132	0.785	2.974	1.630	1.009	0.744	0.407	0.332
8	0.453	0.408	1.213	0.496	2.046	0.774	3.163	1.641	0.988	0.718	0.405	0.346
9	0.589	0.438	1.141	0.487	1.939	0.757	3.209	1.698	1.048	0.702	0.410	0.352
10	1.070	0.520	1.071	0.459*	1.786	0.750	3.122	1.738	1.027	0.731	0.427	0.334
11	0.863	0.503	1.013	0.454*	1.626	0.757	2.873	1.721	0.964	0.722	0.411	0.331
12	2.251	0.608	0.926	0.451*	1.479	0.764	2.634	1.692	0.925	0.672	0.412	0.334
13	1.630	0.653	0.887	0.449*	1.387	0.740	2.497	1.664	0.898	0.649	0.404	0.365
14	2.704	0.637	0.868	0.446*	1.298	0.711	2.517	1.545	1.010	0.640	0.387	0.367
15	1.729	0.622	0.887	0.444*	1.222	0.684	2.672	1.401	1.033	0.617	0.370	0.432
16	1.102	0.607	0.887	0.441*	1.159	0.684	2.483	1.376	0.944	0.599	0.370	0.556
17	0.895	0.578	0.865	0.439*	1.110	0.684	2.304	1.332	0.898	0.615	0.366	0.462
18	0.768	0.549	0.894	0.437*	1.080	0.684	2.100	1.269	0.836	0.610	0.356	0.416
19	0.717	0.515*	0.894	0.434*	1.040	0.684	1.957	1.231	0.817	0.581	0.361	0.415
20	0.653	0.583*	0.872	0.432*	1.021	0.684	1.894	1.177	0.787	0.550	0.356	0.408
21	0.601	0.578*	0.835	0.429*	1.004	0.684	1.845	1.141	1.128	0.540	0.354	0.408
22	0.556	0.578*	0.813	0.427*	0.980	0.684	1.773	1.141	1.244	0.524	0.370	0.395
23	0.528	0.563*	0.778	0.424*	0.956	0.754	1.655	1.099	1.082	0.511	0.377	0.408
24	0.508	0.563*	0.737*	0.420*	0.952	0.778	1.495	1.181	1.261	0.501	0.366	0.394
25	0.488	0.563*	0.704*	0.417*	0.929	0.744	1.447	1.102	1.326	0.494	0.364	0.372
26	0.474	0.823*	0.668*	0.415*	0.934	0.727	1.447	1.017	1.325	0.500	0.344	0.363
27	0.461	1.256*	0.630*	0.413*	0.925	0.953	1.505	0.952	1.250	0.485	0.345	0.363
28	0.444	1.337*	0.622	0.410*	0.909	1.709	1.432	1.006	1.147	0.475	0.335	0.363
29	0.432	1.146*	0.616	0.408*		1.698	1.381	0.923	1.223	0.468	0.327	0.363
30	0.424	0.976*	0.592	0.408*		1.816	1.346	0.840	1.108	0.455	0.338	0.363
31	0.413		0.569	0.502*		1.876		0.886		0.444	0.365	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	23.005	18.571	30.223	14.269	36.586	27.922	63.093	41.594	31.575	19.823	11.918	11.421
TOTAL FLOW (cms days)	0.651	0.526	0.856	0.404	1.036	0.791	1.787	1.178	0.894	0.561	0.338	0.323
TOTAL DEPTH (in)	0.588	0.475	0.773	0.365	0.935	0.714	1.613	1.063	0.807	0.507	0.305	0.292
TOTAL DEPTH (cm)	1.494	1.206	1.963	0.927	2.376	1.813	4.097	2.701	2.050	1.287	0.774	0.742

ANNUAL SUMMARY:
Sum of Mean Daily Flow 330.001 cfs = 9.346 cms
Total Depth 8.437 in = 21.429 cm
Maximum Instantaneous Flow 3.209 cfs = 0.091 cms on April 9 at 24.00 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 12
WATERSHED AREA: 931 ACRES (376 HECTARES)

WATER YEAR 1964
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.365	0.417	0.438	0.454	0.390	0.389	2.164	3.452	1.123	1.036	0.563	0.554
2	0.369	0.417	0.445	0.404*	0.372	0.389	1.786	3.416	1.098	0.998	0.539	0.536
3	0.368	0.417	0.528	0.372	0.363	0.389	1.502	3.176	1.005	0.954	0.988	0.501
4	0.367	0.459	0.514	0.369	0.372	0.389	1.731	2.901	1.005	0.988	0.479	0.449
5	0.397	0.470	0.495	0.371	0.374	0.389	1.983	2.898	1.159	0.983	0.458	0.420
6	0.415	0.552	0.477	0.369	0.365	0.389	1.749	2.859	1.098	0.874	0.462	0.413
7	0.399	0.433	0.461	0.367*	0.363	0.389	1.622	3.032	1.285	0.833	0.472	0.414
8	0.380	0.458	0.446	0.367*	0.363	0.389	1.820	3.174	1.774	0.813	0.480	0.391
9	0.385	0.537	0.432	0.367*	0.367	0.389	2.217	3.226	1.523	0.782	0.453	0.394
10	0.396	0.490	0.433	0.367*	0.376	0.389	2.763	3.362	1.386	0.757	0.437	0.396
11	0.383	0.469	0.844	0.367*	0.372	0.389	2.695	3.461	1.371	0.727	0.424	0.399
12	0.371	0.456	0.956	0.372	0.363	0.389	2.287	3.402	1.393	0.704	0.418	0.403
13	0.371	0.442	0.895	0.376	0.363	0.389	1.915	3.485	1.367	0.741	0.421	0.403
14	0.374	0.456	0.734	0.376	0.363	0.389	1.902	3.471	1.293	0.706	0.417	0.398
15	0.381	0.495	0.648	0.376	0.363	0.389	2.246	3.167	1.219	0.715	0.409	0.392
16	0.380	0.461	0.559	0.376	0.363	0.385	2.420	3.053	1.263	0.692	0.403	0.384
17	0.376	0.451	0.497	0.376	0.363	0.484	2.308	3.011	1.232	0.669	0.399	0.387
18	0.376	0.446	0.487	0.376	0.363	0.497	2.090	2.761	1.233	0.636	0.385	0.402
19	0.385	0.437	0.472	0.378	0.363	0.497	2.027	2.530	1.333	0.619	0.489	0.392
20	0.394	0.427	0.437	0.427	0.363	0.497	2.107	2.453	1.376	0.612	0.456	0.424
21	0.394	0.427	0.408*	0.432	0.363	0.497	2.178	2.373	1.584	0.574	0.425	0.439
22	0.389	0.427	0.396	0.432	0.363	0.497	2.183	2.302	1.575	0.566	0.405	0.413
23	0.593	0.427	0.385	0.432	0.383	0.497	2.085	2.173	1.521	0.557	0.386	0.399
24	0.477	0.427	0.380	0.432	0.401	0.497	1.894	2.014	1.429	0.549	0.377	0.394
25	0.500	0.427	0.380	0.432	0.388	0.497	1.737	1.871	1.356	0.524	0.382	0.381
26	0.446	0.467	0.369	0.429*	0.392	0.497	1.658	1.586	1.317	0.516	0.451	0.369
27	0.437	0.522	0.363	0.427*	0.389	0.490	1.624	1.505	1.255	0.504	0.434	0.371
28	0.434	0.495	0.363	0.415*	0.389	0.521	1.671	1.484	1.176	0.526	0.487	0.371
29	0.432	0.462	0.365	0.401*	0.389	0.719	2.195	1.403	1.122	0.550	0.447	0.374
30	0.424	0.439	0.372	0.396		1.237	3.191	1.269	1.099	0.590	0.412	0.378
31	0.417		0.380	0.396		1.732		1.195		0.556	0.566	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	12.578	13.709	15.359	12.230	10.796	15.885	61.750	81.468	38.973	21.850	14.323	12.342
TOTAL FLOW (cms days)	0.356	0.388	0.435	0.346	0.306	0.450	1.749	2.307	1.104	0.619	0.406	0.350
TOTAL DEPTH (in)	0.322	0.350	0.393	0.313	0.276	0.406	1.579	2.083	0.996	0.559	0.366	0.316
TOTAL DEPTH (cm)	0.817	0.890	0.997	0.794	0.701	1.032	4.010	5.290	2.531	1.419	0.930	0.801

ANNUAL SUMMARY:
Sum of Mean Daily Flow 311.263 cfs = 8.815 cms
Total Depth 7.958 in = 20.212 cm
Maximum Instantaneous Flow 3.517 cfs = 0.100 cms on May 13 at 24.00 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 12
WATERSHED AREA: 931 ACRES (376 HECTARES)

WATER YEAR 1965
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.385	0.402	0.519	0.867	3.662*	2.541*	1.870	6.503*	1.652	1.110	0.515	0.497
2	0.399	0.437	0.519	0.752	2.524*	1.942*	2.605	5.954*	1.630	1.006	0.552	0.490
3	0.406	0.424	0.495	0.740	1.794*	1.530*	2.863	5.404*	1.596	0.936	0.586	0.483
4	0.401	0.406	0.454	0.672	1.366*	1.357*	3.202	4.892*	1.547	0.911	0.544	0.479
5	0.399	0.392	0.417	0.650	1.190*	1.215*	3.868	4.424*	1.505	0.873	0.514	0.490
6	0.396	0.389	0.396*	0.800	1.145*	1.363*	4.090	4.064	1.461	0.831	0.496	0.500
7	0.394	0.389	0.392*	0.862	1.052	1.735*	4.149	3.788	1.410	0.800	0.493	0.503
8	0.405	0.387	0.392	0.803	0.948	2.180*	4.401	3.570	1.357	0.809	0.489	0.819
9	0.401	0.389	0.383	0.750	0.880	2.473*	4.554	3.310	1.319	0.825	0.488	0.593
10	0.394	0.396	0.390	0.711	0.793	2.648	4.588	3.174	1.310	0.774	0.492	0.538
11	0.392	0.394	0.387	0.659	0.894	2.742	4.327	3.120	1.300	0.752	0.493	0.522
12	0.389	0.394	0.378	0.599	0.726	2.680	4.137	3.117	1.430	0.778	0.660	0.519
13	0.389	0.389	0.372	0.555	0.668	2.529	4.554	3.156	1.326	0.731	0.643	0.535
14	0.389	0.380	0.363	0.546	0.662	2.512	5.067	3.213	1.316	0.703	0.551	0.585
15	0.425	0.364	0.363	0.546	0.626	2.542	5.538	3.201	1.283	0.667	0.533	0.708
16	0.425	0.363*	0.363*	0.538	0.575	2.564	6.009	3.152	1.463	0.654	0.523	0.679
17	0.401	0.363*	0.376*	0.530	0.581	2.483	5.939	2.995	1.401	0.671	0.511	0.622
18	0.399	0.372	0.406*	0.527	0.572	2.338*	5.405	2.863	1.316	0.687	0.506	0.604
19	0.399	0.383	0.439*	0.527	0.598	2.173*	5.719	2.699	1.239	0.652	0.532	0.586
20	0.399	0.374	0.469*	0.530	0.675	2.040	10.217	2.545	1.142	0.656	0.543	0.566
21	0.399	0.363	0.804*	0.532	0.792	1.938	10.941	2.424	1.083	0.699	0.605	0.555
22	0.399	0.363	3.406	0.535	0.820	1.816	9.935	2.444	1.051	0.656	0.599	0.517
23	0.392	0.374	5.621	0.540	0.810	1.721	8.838	2.572	1.066	0.641	0.566	0.477
24	0.385	0.503	4.119	0.721	0.781	1.609*	8.333	2.424	1.175	0.632	0.560	0.466
25	0.385	0.661	3.262	0.643	0.765	1.510*	7.807	2.263	1.052	0.627	0.584	0.459
26	0.385	0.465	2.214	0.607	0.817	1.473	7.277	2.124	1.021	0.639	0.598	0.456
27	0.385	0.415	1.938	0.586	2.291*	1.407	7.034	2.007	0.992	0.644	0.548	0.449
28	0.385	0.408	1.634	0.614	2.871*	1.322	6.912	1.892	0.952	0.618	0.553	0.444
29	0.385	0.406	1.351	2.115*		1.292	7.059	1.803	0.948	0.599	0.527	0.446
30	0.385	0.439	1.125	3.184*		1.288	6.833	1.754	1.008	0.573	0.522	0.449
31	0.385		0.958	4.378*		1.427		1.642		0.535	0.523	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	12.253	12.184	34.703	27.620	31.878	60.389	174.072	98.492	38.353	22.688	16.849	16.035
TOTAL FLOW (cms days)	0.347	0.345	0.983	0.782	0.903	1.710	4.930	2.789	1.086	0.643	0.477	0.454
TOTAL DEPTH (in)	0.313	0.311	0.887	0.706	0.815	1.544	4.450	2.518	0.981	0.580	0.431	0.410
TOTAL DEPTH (cm)	0.796	0.791	2.254	1.794	2.070	3.921	11.304	6.396	2.491	1.473	1.094	1.041

ANNUAL SUMMARY:
Sum of Mean Daily Flow 545.517 cfs = 15.449 cms
Total Depth 13.947 in = 35.424 cm
Maximum Instantaneous Flow 11.512 cfs = 0.326 cms on April 20 at 17.00 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 12
WATERSHED AREA: 931 ACRES (376 HECTARES)

WATER YEAR 1966
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.454	0.487	0.461	0.399	0.415	0.508	3.803	1.111*	0.548	0.395	0.259	0.281
2	0.456	0.484	0.456	0.399	0.410	0.520	3.249	0.930*	0.564	0.406	0.255	0.277
3	0.456	0.482	0.456	0.396	0.408	0.557	2.790	0.905*	0.543	0.404	0.262	0.274
4	0.480	0.501	0.456	0.396	0.415	0.848	2.551	0.919	0.541	0.393	0.265	0.270
5	0.495	0.508	0.456	0.420	0.424	0.484	2.475	0.890	0.531	0.379	0.261	0.267
6	0.500	0.506	0.456	0.815	0.427	0.434	2.470	0.882	0.508	0.367	0.261	0.267
7	0.500	0.497	0.454	0.691	0.427	0.508	2.460	0.864	0.504	0.357	0.258	0.257
8	0.497	0.477	0.449	0.670	0.420	0.517	2.401	0.853	0.504	0.348	0.265	0.256
9	0.495	0.456	0.443	0.595	0.413	0.725	2.295	0.853	0.505	0.342	0.264	0.248
10	0.490	0.462	0.441	0.544	0.408	1.067	2.345	0.875	0.601	0.339	0.262	0.240
11	0.482	0.521	0.439	0.514	0.403	0.976	2.189	0.894	0.594	0.335	0.261	0.237
12	0.477	0.497	0.437	0.492	0.403	0.947	1.989	0.875	0.538	0.331	0.260	0.252
13	0.477	0.487	0.434	0.487	0.408	1.066	1.816	0.859	0.498	0.325	0.266	0.288
14	0.484	0.492	0.427	0.487	0.410	1.163	1.741	0.891	0.479	0.322	0.265	0.416
15	0.610	0.490	0.424	0.487	0.396	1.165	1.712	0.868	0.472	0.318	0.258	0.429
16	0.549	0.484	0.429	0.472	0.394	1.124	1.715	0.828	0.464	0.304	0.255	0.355
17	0.535	0.503	0.437	0.456	0.414	0.954	1.727	0.791	0.457	0.311	0.252	0.326
18	0.516	0.581	0.446	0.454	0.424	0.859	1.677	0.767	0.440	0.306	0.247	0.309
19	0.522	0.559	0.454	0.449	0.420	0.831	1.494	0.749	0.437	0.298	0.249	0.313
20	0.513	0.519	0.461	0.441	0.420	0.787	1.459	0.732	0.491	0.295	0.253	0.310
21	0.508	0.508	0.466	0.429	0.422	0.749	1.442	0.711	0.459	0.295	0.257	0.292
22	0.508	0.508	0.471	0.417	0.424	0.687	1.367	0.789	0.455	0.291	0.253	0.295
23	0.508	0.508	0.474	0.410	0.427	0.676	1.293	0.740	0.500	0.286	0.246	0.285
24	0.503	0.497	0.464	0.408	0.427	0.722	1.227	0.657	0.554	0.283	0.243	0.284
25	0.492	0.492	0.456	0.385	0.452	0.947	1.204	0.611	0.495	0.280	0.243	0.291
26	0.487	0.490	0.452	0.363	0.524	1.431	1.254	0.588	0.454	0.281	0.333	0.301
27	0.487	0.484	0.437	0.363	0.546	1.888	1.272	0.576	0.426	0.280	0.324	0.313
28	0.487	0.474	0.432	0.363	0.522	2.317	1.260*	0.572	0.409	0.274	0.296	0.303
29	0.487	0.466	0.436	0.363		2.795	1.223*	0.571	0.404	0.272	0.290	0.299
30	0.487	0.466	0.417	0.363		3.450	1.175*	0.566	0.399	0.270	0.317	0.297
31	0.487		0.405	0.390		3.763		0.566		0.266	0.288	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	15.428	14.887	13.830	14.317	12.002	35.465	57.076	24.281	14.774	9.952	8.265	8.831
TOTAL FLOW (cms days)	0.437	0.422	0.392	0.405	0.340	1.004	1.616	0.688	0.418	0.282	0.234	0.250
TOTAL DEPTH (in)	0.394	0.381	0.354	0.366	0.307	0.907	1.459	0.621	0.378	0.254	0.211	0.226
TOTAL DEPTH (cm)	1.002	0.967	0.898	0.930	0.779	2.303	3.706	1.577	0.959	0.646	0.537	0.573

ANNUAL SUMMARY:
Sum of Mean Daily Flow 229.109 cfs = 6.488 cms
Total Depth 5.857 in = 14.878 cm
Maximum Instantaneous Flow 3.987 cfs = 0.113 cms on April 1 at 0.00 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 12
WATERSHED AREA: 931 ACRES (376 HECTARES)

WATER YEAR 1967
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.297	0.354	0.454	0.341	0.908	0.649	1.132	2.024	1.800	0.670	0.414	0.302
2	0.320	0.354	0.467	0.341	0.772	0.704	1.080	1.967	1.643	0.651	0.399	0.296
3	0.325	0.354	0.501	0.341	0.694	0.650	1.138	1.904	1.529	0.646	0.391	0.298
4	0.319	0.356	0.496	0.353	0.647	0.610	1.336	1.873	1.470	0.638	0.384	0.304
5	0.317	0.358	0.623	0.408	0.593	0.578	1.442	1.984	1.433	0.617	0.394	0.305
6	0.309	0.361	0.541	0.354	0.563	0.541*	1.474	2.476	1.409	0.608	0.380	0.340
7	0.305	0.363	0.500	0.350	0.549	0.530	1.662	3.221	1.338	0.595	0.373	0.323
8	0.307	0.363	0.466	0.350	0.522	0.535	1.913	4.521	1.216	0.585	0.375	0.322
9	0.311	0.363	0.451	0.350	0.508	0.532	1.944	5.176	1.156	0.579	0.368	0.330
10	0.309	0.363	0.445	0.350	0.508	0.549	1.958	5.317	1.123	0.563	0.360	0.316
11	0.312	0.363	0.432	0.362	0.497	0.563	2.092	4.738	1.095	0.547	0.351	0.387
12	0.381	0.404	0.438	0.376	0.482	0.563	2.046	4.059	1.069	0.532	0.347	0.437
13	0.371	0.449	0.516	0.378	0.477	0.566	2.009	3.475	1.032	0.532	0.343	0.393
14	0.371	0.434	0.689	0.387	0.466	0.569	2.034	3.086	0.995	0.527	0.344	0.368
15	0.369	0.410	0.611	0.420	0.451	0.566	1.919	3.033	0.944	0.503	0.335	0.358
16	0.365	0.615	0.536	0.444	0.446	0.844	1.822	3.266	0.913	0.499	0.333	0.350
17	0.363	0.465	0.503	0.420	0.437*	1.755	1.727	3.719*	0.948	0.633	0.327	0.344
18	0.363	0.429	0.487	0.408	0.422*	1.811	1.739	4.135	0.936	0.549	0.320	0.341
19	0.363	0.410	0.474	0.403	0.415*	1.588	1.773	3.900	0.863	0.519	0.319	0.331
20	0.363	0.479	0.464	0.541	0.410	1.427	1.768	3.789	0.935	0.498	0.317	0.317
21	0.363	0.505	0.456	0.699	0.403	1.354	1.768	3.678	1.020	0.490	0.319	0.314
22	0.365	0.477	0.442	0.689	0.403	1.426	1.797	3.684	0.882	0.513	0.319	0.309
23	0.367	0.437	0.422*	0.588	0.403	1.676	1.833	3.646	0.844	0.467	0.317	0.307
24	0.367	0.413	0.413*	0.633	0.401	1.729	1.851	3.453	0.817	0.449	0.312	0.307
25	0.367	0.406	0.403*	0.517	0.408	1.580	1.869	3.116	0.783	0.436	0.309	0.307
26	0.361	0.403	0.399	0.451	0.415	1.537	1.906	2.763	0.761	0.430	0.311	0.307
27	0.354	0.394	0.350*	0.456	0.433	1.510	2.107	2.474	0.761	0.419	0.320	0.308
28	0.354	0.385	0.311	0.727	0.513	1.505	2.180	2.275	0.746	0.416	0.315	0.309
29	0.354	0.410	0.335	1.528		1.428	2.163	2.190	0.724	0.415	0.310	0.311
30	0.354	0.432	0.350	1.662		1.303	2.118	2.106	0.694	0.410	0.306	0.505
31	0.354		0.346	1.149		1.218		1.946		0.433	0.304	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	10.699	12.308	14.320	16.778	14.148	32.398	53.599	98.994	31.878	16.367	10.614	10.047
TOTAL FLOW (cms days)	0.303	0.349	0.406	0.475	0.401	0.918	1.518	2.804	0.903	0.464	0.301	0.285
TOTAL DEPTH (in)	0.274	0.315	0.366	0.429	0.362	0.828	1.370	2.531	0.815	0.418	0.271	0.257
TOTAL DEPTH (cm)	0.695	0.799	0.930	1.089	0.919	2.104	3.481	6.428	2.070	1.063	0.689	0.652

ANNUAL SUMMARY:
Sum of Mean Daily Flow 322.149 cfs = 9.123 cms
Total Depth 8.236 in = 20.919 cm
Maximum Instantaneous Flow 5.553 cfs = 0.157 cms on May 9 at 17.50 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 12
WATERSHED AREA: 931 ACRES (376 HECTARES)

WATER YEAR 1968
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.717*	0.422	0.449	0.533	0.474	2.090	1.279	0.898	0.609	0.416	0.279	0.358
2	0.840*	0.422	0.446	0.513	0.488	2.145	1.395	0.894	0.596	0.414	0.279	0.367
3	1.005*	0.422	0.449	0.517	0.558	2.179	1.288	0.875	0.677	0.401	0.283	0.363
4	1.093*	0.422	0.461	0.508	0.591	2.239	1.260	0.887	0.601	0.389	0.293	0.364
5	1.114*	0.420	0.499	0.503	0.716	2.389	1.344	0.902	0.597	0.384	0.277	0.359
6	1.055*	0.403	0.458	0.495	0.801	2.351	1.245	0.879	0.612	0.378	0.286	0.347
7	0.996*	0.389	0.451	0.698	0.827	2.128	1.241	0.842	0.635	0.381	0.285	0.338
8	0.972*	0.389	0.451	0.538	0.781	1.880	1.219	0.808	0.623	0.356	0.287	0.330
9	0.922*	0.412	0.441	0.482	0.750	1.699	1.227	0.775	0.611	0.322	0.291	0.325
10	0.853*	0.430	0.451	0.540	0.720	1.533	1.242	0.750	0.581	0.402	0.297	0.322
11	0.810*	0.505	0.451	0.469	0.699	1.387	1.357	0.750	0.581	0.339	0.300	0.319
12	0.761*	0.456	0.440	0.461	0.691	1.307	1.386	0.760	0.559	0.354	0.295	0.337
13	0.789*	0.437	0.440*	0.466	0.675	1.250	1.322	0.787	0.566	0.378	0.331	0.324
14	0.817*	0.429	0.432*	0.471	0.644	1.195	1.260	0.779	0.561	0.349	0.401	0.373
15	0.771*	0.429	0.427*	0.504	0.619	1.154	1.213	0.785	0.547	0.345	0.503	0.438
16	0.720*	0.427	0.417	0.537	0.595	1.127	1.168	0.741	0.529	0.348	0.408	0.403
17	0.672*	0.420	0.412	0.503	0.586	1.110	1.110	0.723	0.501	0.360	0.425	0.380
18	0.637*	0.417	0.402	0.497	0.613	1.067	1.063	0.704	0.458	0.356	0.501	0.374
19	0.601*	0.415	0.361	0.497	0.904	1.049	1.037	0.691	0.432	0.357	0.477	0.371
20	0.563*	0.413	0.325	0.500	1.440	1.009	1.021	0.752	0.439	0.357	0.478	0.402
21	0.538*	0.432	0.323	0.500	1.854	0.976	1.013	0.714	0.436	0.377	0.480	0.464
22	0.511*	0.454	0.339	0.500	1.919	0.964	0.982	0.683	0.467	0.368	0.450	0.444
23	0.482*	0.456	0.380	0.505	2.011	1.014	0.942	0.656	0.482	0.362	0.423	0.417
24	0.429	0.465	0.378	0.516	2.263	1.109	0.921	0.634	0.441	0.354	0.398	0.401
25	0.420	0.439	0.469	0.555	2.251	1.192	0.913	0.639	0.420	0.353	0.378	0.399
26	0.417	0.432	0.703	0.542	2.054	1.188	0.909	0.634	0.421	0.347	0.368	0.392
27	0.422	0.562	0.681	0.538	1.847	1.141	0.890	0.623	0.411	0.325	0.370	0.389
28	0.470	0.572	0.644	0.631	1.806	1.110	0.864	0.607	0.413	0.316	0.372	0.387
29	0.441	0.469	0.616	0.660	1.939	1.131	0.857	0.607	0.455	0.315	0.370	0.385
30	0.429	0.459	0.587	0.503		1.208	0.886	0.592	0.435	0.295	0.364	0.383
31	0.424		0.555	0.487		1.231		0.610		0.296	0.359	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	21.693	13.221	14.338	16.170	32.117	44.552	33.853	22.979	15.694	11.095	11.310	11.254
TOTAL FLOW (cms days)	0.614	0.374	0.406	0.458	0.910	1.262	0.959	0.651	0.444	0.314	0.320	0.319
TOTAL DEPTH (in)	0.555	0.338	0.367	0.413	0.821	1.139	0.865	0.587	0.401	0.284	0.289	0.288
TOTAL DEPTH (cm)	1.409	0.859	0.931	1.050	2.086	2.893	2.198	1.492	1.019	0.720	0.734	0.731

ANNUAL SUMMARY:
Sum of Mean Daily Flow 248.275 cfs = 7.031 cms
Total Depth 6.347 in = 16.122 cm
Maximum Instantaneous Flow 2.482 cfs = 0.070 cms on March 5 at 24.00 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 12
WATERSHED AREA: 931 ACRES (376 HECTARES)

WATER YEAR 1969
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.380	0.417	0.482	0.534	0.665	0.567	5.409	1.952	0.727	0.502	0.339	0.311
2	0.378	0.406	0.471	0.456	0.643	0.614	5.795	1.910	0.715	0.478	0.328	0.307
3	0.376	0.411	0.461	0.446	0.631	0.685	6.036	1.805	0.716	0.466	0.328	0.306
4	0.367	0.444	0.464	0.451	0.619	0.751	5.509	1.659	0.708	0.465	0.327	0.317
5	0.358	0.424	0.471	0.542	0.610	0.786	5.724	1.554	0.732	0.463	0.330	0.324
6	0.361	0.415	0.461	0.719	0.610	0.796	5.768	1.469	0.714	0.467	0.333	0.318
7	0.361	0.413	0.451	0.925	0.601	0.750	5.051	1.425	0.665	0.474	0.329	0.310
8	0.358	0.428	0.454	0.899	0.589	0.722	4.399	1.375	0.643	0.456	0.321	0.297
9	0.363	0.578	0.464	0.793	0.583	0.690	4.131	1.313	0.752	0.441	0.319	0.301
10	0.369	0.511	0.546	0.724	0.583	0.671	4.174	1.251	0.732	0.425	0.318	0.314
11	0.407	0.531	0.643	0.681	0.583	0.678	4.099	1.229	0.667	0.432	0.338	0.335
12	0.670	1.177	0.572	0.650	0.609	0.675	3.968	1.197	0.644	0.423	0.329	0.371
13	0.547	0.725	0.550	1.122	0.631	0.705	4.093	1.167	0.632	0.415	0.324	0.358
14	0.456	0.578	0.592	1.806	0.601	0.764	3.865	1.174	0.613	0.408	0.316	0.331
15	0.444	0.530	0.537	1.520	0.592	0.838	3.575	1.242	0.601	0.395	0.309	0.335
16	0.434	0.503	0.555	1.198	0.595	0.904	3.388	1.110	0.572	0.388	0.294	0.339
17	0.417	0.482	0.505	1.018	0.604	1.040	3.288	1.054	0.560	0.382	0.299	0.340
18	0.413	0.482	0.487	0.906	0.624	1.188	3.357	1.016	0.550	0.373	0.331	0.349
19	0.417	0.496	0.479	0.842	0.627	1.185	3.247	1.049	0.553	0.369	0.306	0.433
20	0.427	0.526	0.473	0.806	0.633	1.179	3.034	1.089	0.598	0.358	0.302	0.498
21	0.429	0.558	0.471	1.355	0.647	1.328	2.908	0.973	0.573	0.353	0.306	0.426
22	0.420	0.703	0.471	1.406	0.653	1.527	2.895	0.921	0.559	0.349	0.300	0.393
23	0.417	0.647	0.470	1.170	0.652	1.549	3.008	0.859	0.586	0.345	0.301	0.388
24	0.415	0.595	0.481	1.177	0.624	1.503	3.069	0.847	0.601	0.344	0.293	0.388
25	0.410	0.558	0.492	1.164	0.610	1.566	2.857	0.842	0.569	0.350	0.297	0.395
26	0.403	0.527	0.477	0.940	0.583	1.836	2.620	0.799	0.573	0.339	0.301	0.385
27	0.399	0.516	0.469	0.839	0.551*	2.389	2.377	0.797	0.635	0.334	0.298	0.385
28	0.399	0.505	0.461	0.785	0.550	2.736	2.245	0.782	0.601	0.324	0.305	0.385
29	0.396	0.497	0.442	0.740		3.312	2.158	0.763	0.559	0.322	0.310	0.385
30	0.427	0.492	0.441	0.704		4.183	2.072	0.844	0.529	0.341	0.312	0.418*
31	0.424		0.589	0.684		5.001		0.751		0.339	0.309	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	12.846	16.076	15.384	28.002	17.105	43.117	114.117	36.217	18.879	12.319	9.752	10.742
TOTAL FLOW (cms days)	0.364	0.455	0.436	0.793	0.484	1.221	3.232	1.026	0.535	0.349	0.276	0.304
TOTAL DEPTH (in)	0.328	0.411	0.393	0.716	0.437	1.102	2.917	0.926	0.483	0.315	0.249	0.275
TOTAL DEPTH (cm)	0.834	1.044	0.999	1.818	1.111	2.800	7.410	2.352	1.226	0.800	0.633	0.698

ANNUAL SUMMARY:
Sum of Mean Daily Flow 334.555 cfs = 9.475 cms
Total Depth 8.553 in = 21.725 cm
Maximum Instantaneous Flow 6.365 cfs = 0.180 cms on April 2 at 19.50 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 12
WATERSHED AREA: 931 ACRES (376 HECTARES)

WATER YEAR 1970
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.400*	0.420	0.289*	0.628*	0.799	1.165	1.097	1.198	1.260	1.123	0.416	0.312
2	0.504	0.415	0.302*	0.613	0.731	1.193	1.091	1.236	1.185	1.005	0.406	0.317
3	0.439	0.413	0.295*	0.484*	0.687	1.121	1.049	1.568	1.113	0.925	0.397	0.317
4	0.424	0.410	0.291	0.480*	0.641	1.084	1.049	2.035	1.036	0.868	0.388	0.516
5	0.417	0.461	0.317	0.440*	0.628	1.051	1.093	2.520	0.981	0.842	0.401	0.454
6	0.417	0.472	0.322	0.471*	0.630	1.023	1.331	2.843	0.951	0.837	0.392	0.425
7	0.417	0.466	0.344	0.471*	0.673	1.160	1.951	2.945	0.966	0.772	0.371	0.721
8	0.439	0.440	0.358	0.471*	0.741	1.243	1.990	2.591	0.981	0.718	0.368	0.709
9	0.471	0.429	0.385	0.569	0.766	1.287	1.941	2.442	0.964	0.692	0.379	0.456
10	0.458	0.424	0.415	0.602	0.793	1.343	2.131	2.355	0.947	0.706	0.364	0.419
11	0.457	0.421	0.439	0.410	0.852	1.346	2.213	2.119	0.866	0.688	0.358	0.401
12	0.421	0.419	0.669	0.408	1.005	1.307	2.064	1.955	0.843	0.635	0.357	0.399
13	0.413	0.415	0.628	0.478	1.257	1.269	1.906	1.795	0.848	0.638	0.353	0.406
14	0.413	0.387	0.594	0.585	1.250	1.367	1.763	1.645	0.983	0.609	0.357	0.410
15	0.413	0.361	0.586	0.604	1.155	1.512	1.610	1.569	0.944	0.583	0.343	0.406
16	0.414	0.339	0.543	0.584	1.120	1.543	1.493	1.557	0.905	0.564	0.330	0.387
17	0.424	0.319	0.532	0.596	1.248	1.505	1.421	1.745	0.849	0.549	0.313	0.385
18	0.432	0.294	0.562	0.713	1.149	1.425	1.398	2.150	0.811	0.526	0.309	0.391
19	0.427	0.286	0.609*	0.843	1.061	1.325	1.416	2.328	0.801	0.516	0.311	0.546
20	0.422	0.284	0.701	0.890	1.004	1.288	1.417	2.298	0.766	0.503	0.308	0.492
21	0.422	0.287	1.183	0.873	0.978	1.262	1.410	2.068	0.736	0.508	0.307	0.474
22	0.422	0.288	0.958*	1.007	0.950	1.224	1.357	1.890	0.712	0.511	0.307	0.449*
23	0.422	0.279	0.748	1.502	0.936	1.204	1.301	2.106	0.698	0.490	0.307	0.727*
24	0.422	0.278	0.667	3.039	0.933	1.202	1.269	1.862	0.752	0.462	0.304	0.980*
25	0.422	0.278	0.609	2.013	0.930	1.177	1.241	1.761	0.675	0.457	0.302	0.929*
26	0.420	0.278	0.615	1.398	0.939	1.183	1.226	1.696	0.666	0.442	0.298	0.876*
27	0.423	0.296	0.607	1.461	0.987	1.172	1.217	1.627	1.044	0.433	0.294	0.824*
28	0.472	0.350	0.576	1.320	1.034	1.183	1.204	1.563	1.078	0.442	0.290	0.782*
29	0.443	0.512	0.727	1.085		1.199	1.190	1.514	1.318	0.441	0.289	0.730*
30	0.426	0.326	0.712	0.924		1.178	1.196	1.465	1.270	0.435	0.293	0.684*
31	0.422		0.734	0.831		1.135		1.345		0.429	0.308	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	13.338	11.048	17.319	26.794	25.877	38.676	44.034	59.791	27.949	19.350	10.520	16.324
TOTAL FLOW (cms days)	0.378	0.313	0.490	0.759	0.733	1.095	1.247	1.693	0.792	0.548	0.298	0.462
TOTAL DEPTH (in)	0.341	0.282	0.443	0.685	0.662	0.989	1.126	1.529	0.715	0.495	0.269	0.417
TOTAL DEPTH (cm)	0.866	0.717	1.125	1.740	1.680	2.512	2.859	3.883	1.815	1.257	0.683	1.060

ANNUAL SUMMARY:
Sum of Mean Daily Flow 311.021 cfs = 8.808 cms
Total Depth 7.951 in = 20.197 cm
Maximum Instantaneous Flow 3.424 cfs = 0.097 cms on January 24 at 10.50 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 12
WATERSHED AREA: 931 ACRES (376 HECTARES)

WATER YEAR 1971
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	1.447*	0.604*	0.665	0.459	2.088*	0.970	3.553	5.242	1.755	-----	-----	-----
2	1.392*	0.569*	0.636	0.456	2.411*	0.998	3.581	5.602	1.675	-----	-----	-----
3	1.303*	0.535*	0.619	0.456	2.220*	1.029	3.812	6.123	0.000	-----	-----	-----
4	1.236*	0.505*	0.596	0.610*	2.060*	0.998	4.124	6.472	-----	-----	-----	-----
5	1.181*	0.492*	0.573	0.810*	1.920*	0.971	4.806	6.615	-----	-----	-----	-----
6	1.119*	0.523	0.631	1.087*	1.786*	0.916	5.949	6.268	-----	-----	-----	-----
7	1.050*	0.527	0.818	1.207*	1.659*	0.925	7.213	5.922	-----	-----	-----	-----
8	1.000*	0.519	1.194	1.063*	1.553*	0.941	6.999	5.573	-----	-----	-----	-----
9	0.941*	0.535	1.011	1.009*	1.448*	0.938	6.663	5.256	-----	-----	-----	-----
10	0.921*	0.557	0.858	0.960*	1.291	0.935	6.796	4.997	-----	-----	-----	-----
11	0.910*	0.535	0.777	0.902*	1.216	0.966	6.439	4.783	-----	-----	-----	-----
12	0.857*	0.544	0.713	0.853*	1.219	1.194	5.731	4.606	-----	-----	-----	-----
13	0.820*	0.522	0.720	0.810*	1.341	1.204	5.313	4.520	-----	-----	-----	-----
14	0.778*	0.502	0.641	0.761*	1.530	1.185	5.509	4.244	-----	-----	-----	-----
15	0.724*	0.495	0.587	0.779*	1.777	1.154	6.475	3.947	-----	-----	-----	-----
16	0.681*	0.500	0.581	0.838*	1.853	1.129	6.437	3.765	-----	-----	-----	-----
17	0.647*	0.500	0.550	0.968*	1.876	1.123	6.125	3.423	-----	-----	-----	-----
18	0.610*	0.500	0.518	1.101*	1.819	1.106	5.542	3.158	-----	-----	-----	-----
19	0.572*	0.505	0.508	1.301*	1.721	1.077	5.018	2.974	-----	-----	-----	-----
20	0.538*	0.503	0.505	2.071*	1.572	1.123	5.115	2.688	-----	-----	-----	-----
21	0.676*	0.488	0.492	2.501*	1.468	1.221	5.462	2.362	-----	-----	-----	-----
22	0.849*	0.496	0.477	2.119*	1.394	1.320	5.605	2.156	-----	-----	-----	-----
23	0.875*	0.501	0.462	1.782*	1.316	1.513	5.643	2.034	-----	-----	-----	-----
24	0.902*	1.070	0.461	1.608*	1.302	2.037	5.438	1.864	-----	-----	-----	-----
25	0.902*	1.069	0.461	1.500*	1.255	2.380	5.168	1.797	-----	-----	-----	-----
26	0.857*	0.847	0.461	1.397*	1.138	3.410	4.937	1.738	-----	-----	-----	-----
27	0.810*	0.746	0.461	1.317*	1.099	3.899	4.787	1.671	-----	-----	-----	-----
28	0.768*	0.705	0.459	1.250*	1.047	3.405	4.724	1.716	-----	-----	-----	-----
29	0.717*	0.669	0.459	1.186*		3.203	4.811	1.661	-----	-----	-----	-----
30	0.668*	0.701	0.461	1.186*		3.498	5.052	1.780	-----	-----	-----	-----
31	0.637*		0.467	1.438*		3.745		1.709		-----	-----	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	27.389	17.764	18.822	35.785	44.379	50.513	162.828	116.668	3.431	0.000	0.000	0.000
TOTAL FLOW (cms days)	0.776	0.503	0.533	1.013	1.257	1.431	4.611	3.304	0.097	0.000	0.000	0.000
TOTAL DEPTH (in)	0.700	0.454	0.481	0.915	1.135	1.291	4.163	2.983	0.088	0.000	0.000	0.000
TOTAL DEPTH (cm)	1.779	1.154	1.222	2.324	2.882	3.280	10.574	7.576	0.223	0.000	0.000	0.000

ANNUAL SUMMARY:
Sum of Mean Daily Flow 477.579 cfs = 13.525 cms
Total Depth 12.210 in = 31.012 cm
Maximum Instantaneous Flow 7.449 cfs = 0.211 cms on April 7 at 19.58hours

* Indicates some data were estimated during this day.
Summaries exclude missing data.

TAILHOLT CREEK STUDY AREA
WATERSHED: 12
WATERSHED AREA: 931 ACRES (376 HECTARES)

WATER YEAR 1975
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	-----	-----	-----	-----	-----	-----	-----	-----	-----	0.842	0.541	0.483
2	-----	-----	-----	-----	-----	-----	-----	-----	-----	0.822	0.528	0.502
3	-----	-----	-----	-----	-----	-----	-----	-----	-----	0.800	0.519	0.478
4	-----	-----	-----	-----	-----	-----	-----	-----	-----	0.788	0.497	0.470
5	-----	-----	-----	-----	-----	-----	-----	-----	-----	0.779	0.488	0.465
6	-----	-----	-----	-----	-----	-----	-----	-----	-----	0.777	0.480	0.453
7	-----	-----	-----	-----	-----	-----	-----	-----	-----	0.778	0.588	0.443
8	-----	-----	-----	-----	-----	-----	-----	-----	-----	0.749	0.507	0.439
9	-----	-----	-----	-----	-----	-----	-----	-----	-----	0.722	0.497	0.437
10	-----	-----	-----	-----	-----	-----	-----	-----	-----	0.719	0.486	0.437
11	-----	-----	-----	-----	-----	-----	-----	-----	-----	0.699	0.477	0.433
12	-----	-----	-----	-----	-----	-----	-----	-----	-----	0.735	0.473	0.430
13	-----	-----	-----	-----	-----	-----	-----	-----	-----	0.750	0.466	0.424
14	-----	-----	-----	-----	-----	-----	-----	-----	-----	0.689	0.463	0.425
15	-----	-----	-----	-----	-----	-----	-----	-----	-----	0.665	0.467	0.429
16	-----	-----	-----	-----	-----	-----	-----	-----	-----	0.650	0.454	0.428
17	-----	-----	-----	-----	-----	-----	-----	-----	-----	0.653	0.504	0.440
18	-----	-----	-----	-----	-----	-----	-----	-----	0.991	0.671	0.598	0.439
19	-----	-----	-----	-----	-----	-----	-----	-----	1.047	0.658	0.743	0.442
20	-----	-----	-----	-----	-----	-----	-----	-----	1.035	0.633	0.693	0.447
21	-----	-----	-----	-----	-----	-----	-----	-----	0.960	0.612	0.554	0.438
22	-----	-----	-----	-----	-----	-----	-----	-----	0.887	0.605	0.475	0.438
23	-----	-----	-----	-----	-----	-----	-----	-----	0.898	0.580	0.505	0.436
24	-----	-----	-----	-----	-----	-----	-----	-----	1.033	0.563	0.452	0.425
25	-----	-----	-----	-----	-----	-----	-----	-----	1.023	0.556	0.488	0.424
26	-----	-----	-----	-----	-----	-----	-----	-----	1.016	0.547	0.499	0.428
27	-----	-----	-----	-----	-----	-----	-----	-----	0.951	0.550	0.484	0.427
28	-----	-----	-----	-----	-----	-----	-----	-----	0.916	0.541	0.509	0.431
29	-----	-----	-----	-----		-----	-----	-----	0.886	0.548	0.499	0.432
30	-----	-----	-----	-----		-----	-----	-----	0.859	0.544	0.473	0.428
31	-----		-----	-----		-----		-----		0.546	0.461	
MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	12.502	20.768	15.868	13.250
TOTAL FLOW (cms days)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.354	0.588	0.449	0.375
TOTAL DEPTH (in)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.320	0.531	0.406	0.339
TOTAL DEPTH (cm)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.812	1.349	1.030	0.860

ANNUAL SUMMARY:
Sum of Mean Daily Flow 62.388 cfs = 1.767 cms
Total Depth 1.595 in = 4.051 cm
Maximum Instantaneous Flow 1.366 cfs = 0.039 cms on August 19 at 20.00 hours

* Indicates some data were estimated during this day.
Summaries exclude missing data.

TAILHOLT CREEK STUDY AREA
WATERSHED: 12
WATERSHED AREA: 931 ACRES (376 HECTARES)

WATER YEAR 1976
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.431	0.578	0.506	0.508	0.569	0.674	1.153	2.399	1.327	0.728	0.664	0.453
2	0.426	0.563	0.505	0.499	0.582	0.628	1.154	2.479	1.271	0.716	0.659	0.448
3	0.421	0.555	0.504	0.489	0.591	0.616	1.184	2.520	1.251	0.707	0.669	0.447
4	0.437	0.540	0.506	0.487	0.571	0.615	1.426	2.581	1.207	0.698	0.665	0.442
5	0.433	0.517	0.504	0.491	0.600	0.585	1.865	2.641	1.177	0.684	0.657	0.437
6	0.622	0.513	0.505	0.490	0.456	0.555	2.257	2.692	1.165	0.671	0.650	0.546
7	0.708	0.548	0.504	0.486	0.455	0.573	2.739	2.745	1.150	0.662	0.642	0.485
8	0.495	0.517	0.505	0.495	0.508	0.590	3.657	2.790	1.157	0.649	0.716	0.469
9	0.459	0.511	0.508	0.495	0.526	0.656	5.619	2.827	1.158	0.636	0.703	0.462
10	0.446	0.513	0.508	0.479	0.513	0.877	5.555	2.865	1.259	0.620	0.655	0.459
11	0.520	0.517	0.511	0.479	0.512	0.970	5.106	2.884	1.407	0.609	0.628	0.506
12	0.509	0.506	0.507	0.479	0.510	0.928	5.110	2.908	1.339	0.710	0.631	0.546
13	0.490	0.493	0.517	0.474	0.502	0.892	5.107	2.870	1.607	0.636	0.624	0.509
14	0.472	0.506	0.544	0.475	0.508	0.835	4.881	2.751	1.365	0.595	0.622	0.488
15	0.464	0.684	0.571	0.565	0.499	0.784	4.518	2.638	1.278	0.573	0.631	0.481
16	0.464	0.806	0.601	0.573	0.498	0.772	3.937	2.527	1.206	0.567	0.657	0.499
17	0.461	0.702	0.630	0.566	0.510	0.788	3.549	2.420	1.057	0.598	0.618	0.548
18	0.457	0.625	1.532	0.571	0.504	0.919	3.317	2.307	0.988	0.692	0.637	0.535
19	0.449	0.566	2.035	0.566	0.497	0.932	2.993	2.200	0.936	0.684	0.639	0.529
20	0.439	0.554	1.100	0.586	0.487	0.915	2.865	2.088	0.958	0.671	0.596	0.517
21	0.692	0.534	0.665	0.596	0.474	0.891	2.786	1.977	0.995	0.712	0.561	0.503
22	0.629	0.506	0.584	0.565	0.475	0.930	2.774	1.863	0.939	0.704	0.601	0.654
23	0.526	0.506	0.570	0.564	0.475	0.929	2.382	1.747	0.907	0.688	0.567	0.583
24	0.513	0.518	0.572	0.545	0.479	1.021	2.359	1.632	0.893	0.728	0.518	0.548
25	0.520	0.514	0.566	0.536	0.487	0.982	2.359	1.622	0.872	0.658	0.489	0.536
26	0.787	0.508	0.591	0.533	0.577	0.953	2.350	1.482	0.864	0.634	0.553	0.526
27	0.668	0.511	0.577	0.535	0.646	0.933	2.359	1.403	0.837	0.625	0.520	0.510
28	0.597	0.508	0.601	0.533	0.699	0.890	2.345	1.533	0.794	0.612	0.510	0.505
29	0.588	0.505	0.544	0.531	0.699	0.850	2.349	1.379	0.757	0.619	0.480	0.500
30	0.637	0.505	0.548	0.537		0.895	2.343	1.333	0.733	0.629	0.468	0.495
31	0.610		0.522	0.551		1.016		1.398		0.629	0.461	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	16.369	16.430	19.941	16.279	15.410	25.394	92.397	69.503	32.857	20.346	18.689	15.166
TOTAL FLOW (cms days)	0.464	0.465	0.565	0.461	0.436	0.719	2.617	1.968	0.931	0.576	0.529	0.430
TOTAL DEPTH (in)	0.418	0.420	0.510	0.416	0.394	0.649	2.362	1.777	0.840	0.520	0.478	0.388
TOTAL DEPTH (cm)	1.063	1.067	1.295	1.057	1.001	1.649	6.000	4.513	2.134	1.321	1.214	0.985

ANNUAL SUMMARY:
Sum of Mean Daily Flow 358.782 cfs = 10.161 cms
Total Depth 9.173 in = 23.298 cm
Maximum Instantaneous Flow 5.895 cfs = 0.167 cms on April 9 at 15.00 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 12
WATERSHED AREA: 931 ACRES (376 HECTARES)

WATER YEAR 1977
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.494	0.520	0.508	0.290	0.408	0.408	0.367	0.492	0.465	0.279	0.244	0.250
2	0.527	0.545	0.511	0.253	0.408	0.408	0.379	0.513	0.445	0.283	0.247	0.232
3	0.539	0.527	0.525	0.377	0.408	0.408	0.369	0.492	0.435	0.432	0.257	0.224
4	0.517	0.516	0.537	0.410	0.408	0.408	0.379	0.490	0.414	0.344	0.247	0.224
5	0.513	0.514	0.539	0.411	0.408	0.408	0.418	0.480	0.392	0.313	0.244	0.221
6	0.513	0.514	0.509	0.409	0.408	0.408	0.481	0.477	0.381	0.296	0.294	0.219
7	0.512	0.518	0.502	0.408	0.408	0.408	0.622	0.485	0.386	0.285	0.264	0.217
8	0.508	0.513	0.638	0.408	0.408	0.408	0.750	0.473	0.473	0.282	0.255	0.215
9	0.508	0.513	0.698	0.408	0.408	0.435	0.663	0.475	0.412	0.287	0.251	0.221
10	0.505	0.510	0.663	0.408	0.408	0.436	0.580	0.476	0.428	0.282	0.244	0.220
11	0.502	0.505	0.632	0.408	0.408	0.447	0.540	0.465	0.472	0.272	0.243	0.218
12	0.500	0.506	0.598	0.408	0.408	0.446	0.526	0.452	0.402	0.267	0.239	0.219
13	0.497	0.509	0.565	0.408	0.408	0.444	0.510	0.450	0.360	0.263	0.233	0.219
14	0.498	0.509	0.539	0.408	0.408	0.440	0.489	0.446	0.353	0.263	0.236	0.220
15	0.503	0.512	0.440	0.408	0.408	0.561	0.469	0.448	0.340	0.259	0.241	0.305
16	0.507	0.508	0.437	0.408	0.408	0.480	0.467	0.515	0.334	0.251	0.231	0.323
17	0.502	0.508	0.432	0.408	0.408	0.444	0.461	0.557	0.329	0.250	0.228	0.344
18	0.492	0.508	0.432	0.408	0.408	0.426	0.442	0.571	0.316	0.257	0.230	0.281
19	0.493	0.514	0.440	0.408	0.408	0.416	0.430	0.565	0.327	0.295	0.238	0.268
20	0.496	0.508	0.449	0.408	0.408	0.409	0.418	0.519	0.354	0.263	0.239	0.320
21	0.494	0.508	0.477	0.408	0.408	0.406	0.414	0.496	0.348	0.266	0.243	0.333
22	0.498	0.510	0.471	0.408	0.408	0.412	0.413	0.483	0.319	0.272	0.264	0.320
23	0.494	0.510	0.435	0.408	0.408	0.428	0.414	0.510	0.307	0.272	0.255	0.315
24	0.496	0.513	0.419	0.408	0.408	0.438	0.413	0.539	0.299	0.314	0.268	0.392
25	0.523	0.511	0.416	0.408	0.408	0.407	0.410	0.537	0.297	0.351	0.318	0.347
26	0.539	0.493	0.415	0.408	0.408	0.398	0.406	0.507	0.289	0.284	0.346	0.339
27	0.525	0.553	0.413	0.408	0.408	0.398	0.408	0.562	0.286	0.273	0.327	0.304
28	0.524	1.015	0.398	0.408	0.408	0.396	0.425	0.527	0.286	0.262	0.288	0.310
29	0.524	0.731	0.394	0.408		0.378	0.461	0.507	0.286	0.253	0.285	0.449
30	0.526	0.549	0.396	0.408		0.369	0.459	0.491	0.280	0.254	0.333	0.402
31	0.522		0.370	0.408		0.367		0.482		0.250	0.279	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	15.793	16.169	15.196	12.354	11.429	13.045	13.984	15.482	10.816	8.773	8.108	8.472
TOTAL FLOW (cms days)	0.447	0.458	0.430	0.350	0.324	0.369	0.396	0.438	0.306	0.248	0.230	0.240
TOTAL DEPTH (in)	0.404	0.413	0.388	0.316	0.292	0.334	0.358	0.396	0.277	0.224	0.207	0.217
TOTAL DEPTH (cm)	1.026	1.050	0.987	0.802	0.742	0.847	0.908	1.005	0.702	0.570	0.527	0.550

ANNUAL SUMMARY:

Sum of Mean Daily Flow	149.621 cfs =	4.237 cms
Total Depth	3.825 in =	9.716 cm
Maximum Instantaneous Flow	1.356 cfs =	0.038 cms on November 28 at 13.00 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 12
WATERSHED AREA: 931 ACRES (376 HECTARES)

WATER YEAR 1978
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.346	0.334	0.376	0.525	0.690	1.185	3.161	1.397	0.887	0.731	0.530	0.351
2	0.322	0.338	0.494	0.720	0.689	1.193	2.850	1.393	0.897	0.703	0.520	0.344
3	0.306	0.339	0.579	0.787	0.692	1.201	2.375	1.368	0.921	0.728	0.511	0.336
4	0.290	0.338	0.561	0.779	0.697	1.208	2.068	1.321	0.906	0.732	0.502	0.331
5	0.289	0.342	0.487	0.784	0.709	1.199	1.950	1.291	0.858	0.722	0.508	0.343
6	0.288	0.342	0.456	0.800	0.810	1.198	1.913	1.258	0.908	0.661	0.491	0.397
7	0.336	0.337	0.441	0.697	0.928	1.203	1.917	1.224	0.893	0.643	0.469	0.464
8	0.302	0.333	0.404	0.609	1.065	1.254	1.839	1.180	0.896	0.712	0.460	0.384
9	0.294	0.317	0.373	0.601	1.112	1.321	1.785	1.130	0.911	0.755	0.457	0.353
10	0.286	0.313	0.385	0.616	1.095	1.416	1.723	1.081	0.915	0.720	0.455	0.374
11	0.278	0.315	0.479	0.619	1.031	1.446	1.683	1.065	0.935	0.756	0.441	0.446
12	0.278	0.314	0.507	0.619	0.951	1.437	1.668	1.055	0.933	0.755	0.433	0.500
13	0.278	0.320	0.675	0.600	0.891	1.310	1.581	1.055	0.923	0.739	0.550	0.556
14	0.278	0.326	1.461	0.598	0.874	1.140	1.464	1.066	0.879	0.693	0.520	0.608
15	0.280	0.335	2.695	0.607	0.872	1.100	1.464	1.091	0.848	0.672	0.477	0.608
16	0.279	0.340	1.524	0.623	0.854	1.040	1.441	1.122	0.808	0.648	0.514	0.607
17	0.282	0.326	1.021	0.659	0.789	1.038	1.360	1.163	0.754	0.622	0.487	0.611
18	0.280	0.306	0.828	0.714	0.785	1.457	1.247	1.204	0.701	0.612	0.458	0.636
19	0.282	0.314	0.712	0.784	0.780	1.896	1.207	1.256	0.678	0.587	0.431	0.626
20	0.284	0.486	0.637	0.799	0.758	2.116	1.185	1.302	0.731	0.543	0.419	0.605
21	0.282	0.725	0.608	0.799	0.759	2.381	1.189	1.324	0.739	0.514	0.407	0.596
22	0.288	0.561	0.591	0.799	0.822	2.571	1.196	1.340	0.789	0.487	0.448	0.585
23	0.291	0.432	0.566	0.799	0.937	2.584	1.206	1.341	0.763	0.461	0.441	0.567
24	0.301	0.352	0.546	0.798	1.022	2.532	1.219	1.322	0.781	0.452	0.407	0.562
25	0.411	0.392	0.520	0.810	1.079	2.279	1.251	1.284	0.900	0.447	0.392	0.561
26	0.427	0.473	0.491	0.799	1.184	2.347	1.278	1.241	0.887	0.445	0.390	0.554
27	0.354	0.396	0.482	0.737	1.264	2.580	1.373	1.175	0.845	0.516	0.383	0.540
28	0.343	0.384	0.532	0.693	1.192	2.951	1.402	1.106	0.828	0.607	0.373	0.530
29	0.334	0.388	0.656	0.687		3.104	1.406	1.065	0.777	0.587	0.368	0.530
30	0.331	0.389	0.676	0.687		3.148	1.415	1.029	0.747	0.558	0.368	0.525
31	0.336		0.513	0.690		3.161		0.922		0.540	0.364	

MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	9.558	11.207	21.274	21.835	25.332	55.998	48.817	37.171	25.235	19.348	13.973	15.028
TOTAL FLOW (cms days)	0.271	0.317	0.602	0.618	0.717	1.586	1.383	1.053	0.715	0.548	0.396	0.426
TOTAL DEPTH (in)	0.244	0.287	0.544	0.558	0.648	1.432	1.248	0.950	0.645	0.495	0.357	0.384
TOTAL DEPTH (cm)	0.621	0.728	1.381	1.418	1.645	3.636	3.170	2.414	1.639	1.256	0.907	0.976

ANNUAL SUMMARY:
Sum of Mean Daily Flow 304.776 cfs = 8.631 cms
Total Depth 7.792 in = 19.791 cm
Maximum Instantaneous Flow 3.191 cfs = 0.090 cms on April 1 at 13.00 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 12
WATERSHED AREA: 931 ACRES (376 HECTARES)

WATER YEAR 1979
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.535	0.471	0.456	0.456	0.456	0.630	0.852	1.294	0.659	0.421	0.328	0.309
2	0.570	0.466	0.456	0.456	0.456	0.640	0.819	1.223	0.612	0.414	0.309	0.279
3	0.571	0.465	0.456	0.456	0.456	0.646	0.822	1.221	0.593	0.438	0.301	0.262
4	0.570	0.461	0.456	0.456	0.456	0.707	0.846	1.199	0.554	0.450	0.301	0.268
5	0.573	0.461	0.456	0.456	0.456	0.928	0.861	1.197	0.513	0.437	0.295	0.266
6	0.575	0.463	0.456	0.456	0.456	1.117	0.899	1.188	0.513	0.428	0.293	0.259
7	0.571	0.460	0.456	0.456	0.456	1.012	0.944	1.111	0.517	0.422	0.292	0.256
8	0.569	0.460	0.456	0.456	0.455	0.884	1.075	1.084	0.506	0.398	0.267	0.248
9	0.570	0.461	0.456	0.456	0.456	0.847	1.018	1.018	0.492	0.397	0.229	0.246
10	0.572	0.461	0.456	0.456	0.456	0.901	0.941	0.971	0.476	0.391	0.220	0.254
11	0.567	0.465	0.456	0.456	0.463	0.981	0.906	0.943	0.462	0.389	0.222	0.257
12	0.566	0.466	0.456	0.456	0.469	1.011	0.896	0.906	0.451	0.398	0.245	0.256
13	0.572	0.457	0.456	0.456	0.476	1.055	0.888	0.881	0.438	0.394	0.302	0.257
14	0.573	0.456	0.456	0.456	0.484	1.114	0.955	0.862	0.432	0.389	0.308	0.252
15	0.580	0.453	0.456	0.456	0.494	1.245	1.188	0.853	0.436	0.384	0.270	0.250
16	0.579	0.452	0.456	0.456	0.502	1.144	1.556	0.840	0.440	0.372	0.263	0.246
17	0.572	0.456	0.456	0.456	0.511	1.020	1.271	0.820	0.503	0.355	0.261	0.250
18	0.574	0.453	0.456	0.456	0.520	1.004	1.130	0.799	0.788	0.352	0.273	0.239
19	0.566	0.455	0.456	0.456	0.527	1.033	1.117	0.776	0.564	0.347	0.273	0.242
20	0.570	0.454	0.456	0.456	0.534	1.071	1.185	0.761	0.513	0.341	0.269	0.239
21	0.546	0.453	0.456	0.456	0.544	1.088	1.186	0.743	0.497	0.356	0.265	0.238
22	0.536	0.452	0.456	0.456	0.552	1.095	1.231	0.721	0.481	0.463	0.263	0.241
23	0.529	0.456	0.456	0.456	0.573	1.145	1.304	0.706	0.455	0.391	0.295	0.242
24	0.517	0.456	0.456	0.456	0.583	1.174	1.315	0.721	0.441	0.362	0.320	0.244
25	0.545	0.456	0.456	0.456	0.590	1.121	1.262	0.712	0.428	0.353	0.280	0.254
26	0.548	0.456	0.456	0.456	0.599	1.155	1.234	0.698	0.420	0.347	0.276	0.282
27	0.553	0.454	0.456	0.454	0.610	1.117	1.308	0.703	0.415	0.339	0.287	0.280
28	0.556	0.455	0.456	0.456	0.619	1.042	1.369	0.715	0.404	0.346	0.291	0.272
29	0.539	0.456	0.456	0.456		0.977	1.373	0.736	0.402	0.346	0.289	0.271
30	0.526	0.456	0.456	0.456		0.910	1.354	0.718	0.407	0.335	0.307	0.266
31	0.513		0.456	0.456		0.869		0.697		0.334	0.340	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	17.305	13.749	14.145	14.142	14.213	30.684	33.104	27.818	14.810	11.889	8.735	7.723
TOTAL FLOW (cms days)	0.490	0.389	0.401	0.400	0.403	0.869	0.938	0.788	0.419	0.337	0.247	0.219
TOTAL DEPTH (in)	0.442	0.351	0.362	0.362	0.363	0.784	0.846	0.711	0.379	0.304	0.223	0.197
TOTAL DEPTH (cm)	1.124	0.893	0.919	0.918	0.923	1.993	2.150	1.806	0.962	0.772	0.567	0.502

ANNUAL SUMMARY:
Sum of Mean Daily Flow 208.318 cfs = 5.900 cms
Total Depth 5.326 in = 13.527 cm
Maximum Instantaneous Flow 1.839 cfs = 0.052 cms on April 16 at 1.00 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 12
WATERSHED AREA: 931 ACRES (376 HECTARES)

WATER YEAR 1980
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.265	0.310	0.408	0.325	0.380	0.927	0.704	1.396	0.880	0.573	0.356	0.289
2	0.272	0.307	0.413	0.322	0.389	0.929	0.710	1.281	1.112	0.654	0.341	0.338
3	0.263	0.311	0.417	0.320	0.422	0.910	0.709	1.198	1.079	0.846	0.334	0.329
4	0.265	0.320	0.437	0.319	0.416	0.879	0.718	1.133	1.057	0.679	0.331	0.299
5	0.268	0.347	0.416	0.321	0.402	0.868	0.808	1.099	1.023	0.588	0.321	0.289
6	0.263	0.369	0.417	0.325	0.392	0.834	0.850	1.083	0.981	0.556	0.320	0.283
7	0.264	0.363	0.417	0.328	0.387	0.782	0.848	1.034	0.924	0.534	0.316	0.290
8	0.268	0.360	0.414	0.334	0.400	0.737	0.860	1.025	0.883	0.519	0.312	0.282
9	0.284	0.355	0.408	0.340	0.392	0.695	1.034	1.009	0.843	0.504	0.309	0.275
10	0.285	0.351	0.409	0.350	0.391	0.703	1.151	0.972	0.808	0.483	0.307	0.381
11	0.293	0.356	0.398	0.363	0.393	0.717	1.203	0.884	0.777	0.470	0.300	0.379
12	0.288	0.348	0.387	0.476	0.397	0.674	1.257	0.828	0.792	0.464	0.297	0.323
13	0.288	0.346	0.378	0.691	0.401	0.672	1.373	0.793	0.783	0.460	0.300	0.451
14	0.269	0.348	0.373	1.014	0.406	0.860	1.677	0.768	0.924	0.482	0.304	0.364
15	0.366	0.345	0.374	1.073	0.406	0.911	1.936	0.793	0.842	0.469	0.313	0.325
16	0.307	0.354	0.367	0.791	0.406	0.832	2.040	0.813	0.766	0.438	0.309	0.309
17	0.306	0.382	0.369	0.654	0.419	0.787	2.086	0.754	0.713	0.428	0.299	0.303
18	0.316	0.382	0.371	0.562	0.610	0.782	2.277	0.720	0.683	0.424	0.375	0.450
19	0.433	0.359	0.371	0.522	0.875	0.750	2.330	0.692	0.660	0.419	0.332	0.392
20	0.347	0.351	0.374	0.501	0.959	0.757	2.330	0.660	0.658	0.417	0.326	0.363
21	0.340	0.360	0.382	0.479	0.926	0.813	2.377	0.638	0.655	0.408	0.320	0.365
22	0.334	0.362	0.382	0.450	0.818	0.823	2.212	0.649	0.670	0.398	0.316	0.341
23	0.394	0.365	0.368	0.434	0.742	0.847	2.187	0.835	0.702	0.385	0.309	0.335
24	0.343	0.367	0.383	0.419	0.684	0.826	2.304	0.742	0.691	0.379	0.295	0.327
25	0.356	0.375	0.393	0.409	0.662	0.808	2.137	0.784	0.644	0.369	0.288	0.324
26	0.438	0.376	0.381	0.399	0.738	0.786	1.841	0.846	0.633	0.357	0.282	0.324
27	0.342	0.383	0.371	0.395	0.901	0.775	1.660	0.798	0.619	0.356	0.296	0.334
28	0.333	0.391	0.368	0.399	1.034	0.733	1.630	0.778	0.603	0.358	0.286	0.342
29	0.316	0.391	0.350	0.394	0.962	0.731	1.614	0.808	0.595	0.355	0.286	0.347
30	0.315	0.395	0.343	0.387		0.712	1.509	0.836	0.594	0.348	0.285	0.356
31	0.312		0.332	0.383		0.704		0.847		0.350	0.289	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	9.733	10.729	11.971	14.481	16.712	24.565	46.373	27.495	23.593	14.472	9.654	10.106
TOTAL FLOW (cms days)	0.276	0.304	0.339	0.410	0.473	0.696	1.313	0.779	0.668	0.410	0.273	0.286
TOTAL DEPTH (in)	0.249	0.274	0.306	0.370	0.427	0.628	1.186	0.703	0.603	0.370	0.247	0.258
TOTAL DEPTH (cm)	0.632	0.697	0.777	0.940	1.085	1.595	3.011	1.785	1.532	0.940	0.627	0.656

ANNUAL SUMMARY:
Sum of Mean Daily Flow 219.884 cfs = 6.227 cms
Total Depth 5.621 in = 14.279 cm
Maximum Instantaneous Flow 2.569 cfs = 0.073 cms on April 24 at 21.96 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 12
WATERSHED AREA: 931 ACRES (376 HECTARES)

WATER YEAR 1981
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.364	0.381	0.431	0.896	0.496	0.973	0.844	0.901	1.104	1.005	0.470	0.334
2	0.365	0.379	0.561	0.814	0.484	0.932	0.873	0.900	1.053	0.959	0.460	0.337
3	0.366	0.379	1.132	0.771	0.476	0.901	0.867	0.871	1.022	0.914	0.441	0.327
4	0.367	0.380	1.694	0.742	0.467*	0.885	0.865	0.818	0.986	0.880	0.443	0.318
5	0.367	0.379	1.093	0.685	0.449*	0.869	0.863	0.793	0.967	0.840	0.436	0.324
6	0.367	0.410	0.796	0.630	0.430*	0.845	0.869	0.705	1.087	0.996	0.427	0.329
7	0.367	0.773	0.658*	0.605	0.414	0.811	0.868	0.699	1.124	1.007	0.423	0.326
8	0.366	0.564	0.613*	0.584	0.410*	0.782	0.873	0.692	1.350	0.850	0.416	0.325
9	0.365	0.501	0.584*	0.566	0.416*	0.750	0.898	0.685	1.474	0.796	0.413	0.319
10	0.363	0.502	0.555*	0.551	0.417*	0.728	0.902	0.694	1.453	0.792	0.411	0.313
11	0.362	0.488	0.524*	0.510	0.418*	0.718	0.896	0.735	1.400	0.764	0.388	0.307
12	0.388	0.479	0.510	0.496	0.422	0.720	0.889	0.752	1.581	0.740	0.376	0.298
13	0.420	0.451	0.506	0.495	0.440	0.720	0.876	0.746	1.572	0.713	0.371	0.288
14	0.390	0.426	0.501	0.498	0.580	0.715	0.860	0.837	1.564	0.689	0.368	0.287
15	0.398	0.402	0.495	0.503	0.521	0.712	0.850	1.063	1.525	0.674	0.360	0.289
16	0.404	0.412	0.479	0.507	0.804	0.735	0.846	1.079	1.551	0.656	0.358	0.286
17	0.385	0.438	0.464	0.499	0.966	0.720	0.835	1.051	1.516	0.641	0.358	0.285
18	0.374	0.406	0.459	0.499	0.930	0.690	0.835	1.038	1.408	0.627	0.369	0.284
19	0.371	0.397	0.456	0.500	1.469	0.685	0.848	1.034	1.714	0.605	0.382	0.294
20	0.369	0.388	0.455	0.500	1.828	0.681	0.852	1.120	1.785	0.584	0.377	0.296
21	0.370	0.389	0.501	0.500	1.604	0.673	0.854	1.251	1.761	0.564	0.362	0.305
22	0.370	0.419	0.822	0.500	1.409	0.680	0.847	1.248	1.679	0.554	0.359	0.307
23	0.365	0.404	0.904	0.541	1.296	0.692	0.815	1.265	1.581	0.528	0.361	0.311
24	0.361	0.393	0.897	0.585	1.245	0.670	0.790	1.271	1.468	0.521	0.358	0.311
25	0.421	0.365	1.006	0.530	1.191	0.673	0.783	1.324	1.368	0.522	0.342	0.350
26	0.493	0.367	1.818	0.515	1.154	0.730	0.816	1.269	1.311	0.525	0.328	0.357
27	0.418	0.373	1.940	0.514	1.075	0.739	1.009	1.214	1.237	0.510	0.328	0.380
28	0.398	0.385	1.537	0.518	1.020	0.740	0.943	1.189	1.164	0.498	0.329	0.570
29	0.393	0.412	1.215	0.517		0.747	0.925	1.174	1.103	0.483	0.326	0.364
30	0.385	0.437	1.069	0.512		0.764	0.915	1.213	1.044	0.479	0.332	0.348
31	0.386		1.013	0.506		0.763		1.223		0.474	0.333	
MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	11.880	12.877	25.689	17.588	22.831	23.441	26.006	30.853	40.953	21.390	11.803	9.769
TOTAL FLOW (cms days)	0.336	0.365	0.727	0.498	0.647	0.664	0.736	0.874	1.160	0.606	0.334	0.277
TOTAL DEPTH (in)	0.304	0.329	0.657	0.450	0.584	0.599	0.665	0.789	1.047	0.547	0.302	0.250
TOTAL DEPTH (cm)	0.771	0.836	1.668	1.142	1.483	1.522	1.689	2.004	2.659	1.389	0.766	0.634

ANNUAL SUMMARY:
Sum of Mean Daily Flow 255.080 cfs = 7.224 cms
Total Depth 6.521 in = 16.564 cm
Maximum Instantaneous Flow 2.362 cfs = 0.067 cms on December 4 at 11.41 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 12
WATERSHED AREA: 931 ACRES (376 HECTARES)

WATER YEAR 1982
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.343	0.415	0.471	0.746	0.552	2.999	3.170	7.976	2.474	1.138	0.654	0.452
2	0.343	0.412	0.520	0.722	0.550	3.172	3.014	7.681	2.336	1.091	0.652	0.451
3	0.390	0.409	0.518	0.693	0.549	3.220	2.914	7.878	2.204	1.080	0.636	0.452
4	0.373	0.409	0.516	0.683	0.546*	3.164	2.763	7.754	2.132	1.081	0.621	0.449
5	0.365	0.406	0.549	0.651	0.546*	2.957	2.615	7.409	2.192	1.060	0.614	0.440
6	0.361	0.405	1.074	0.608	0.549*	2.764	2.560	6.877	2.144	1.026	0.592	0.436
7	0.389	0.405	1.305	0.687	0.550*	2.716	2.450	6.619	2.243	1.148	0.585	0.433
8	0.402	0.402	1.052	0.609	0.549*	2.638	2.396	6.489	2.281	1.104	0.627	0.429
9	0.383	0.399	1.018	0.593	0.550*	2.671	2.417	5.946	2.166	1.054	0.640	0.423
10	0.418	0.390	1.442	0.595	0.550*	2.826	2.482*	5.602	2.057	0.999	0.602	0.452
11	0.552	0.387	1.215	0.596	0.547*	3.245	3.787*	5.349	1.951	0.969	0.596	0.454
12	0.480	0.468	1.031	0.584	0.545*	3.327	6.084	5.107	1.865	0.944	0.609	0.524
13	0.424	0.488	0.903	0.575	0.559	3.309	6.920	4.857	1.799	0.923	0.581	0.515
14	0.401	0.581	0.842	0.569	0.783	3.328	7.122	4.813	1.736	0.898	0.566	0.489
15	0.384	0.540	0.865	0.570	0.978	3.308	6.759	4.866	1.635	0.875	0.560	0.492
16	0.374	0.765	0.828	0.571	2.226	3.189	6.177	5.272	1.547	0.855	0.547	0.492
17	0.372	0.840	0.810	0.571	2.549	3.130	5.698	5.142	1.497	0.840	0.540	0.485
18	0.365	0.712	0.818	0.568	2.412	3.081	5.048	4.626	1.442	0.821	0.538	0.481
19	0.365	0.590	1.271	0.561	2.731	2.966	4.544	4.229	1.398	0.803	0.541	0.505
20	0.372	0.540	2.595	0.547	4.199	2.773	4.217	3.960	1.381	0.780	0.539	0.636
21	0.386	0.583	2.007	0.656	8.165	2.661	4.103	3.695	1.362	0.755	0.526	0.535
22	0.385	0.820	1.585	0.579	9.458	2.583	4.549	3.528	1.365	0.738	0.517	0.503
23	0.385	0.744	1.331	0.540	7.039	2.522	5.803	3.410	1.333	0.726	0.492	0.491
24	0.389	0.660	1.198	0.550	5.512	2.555	7.326	3.283	1.265	0.729	0.469	0.496
25	0.389	0.589	1.113	0.540	4.429	2.696	8.040	3.211	1.207	0.727	0.467	0.553
26	0.463	0.551	1.029	0.573	3.794	3.137	8.013	3.907	1.194	0.707	0.463	0.771
27	0.431	0.534	0.947	0.564	3.339	3.300	8.081	3.587	1.142	0.694	0.457	0.663
28	0.426	0.505	0.889	0.561	2.971	3.482	7.885	3.545	1.187	0.697	0.449	0.620
29	0.431	0.491	0.843	0.558		3.414	7.859	3.220	1.102	0.697	0.459	0.766
30	0.419	0.490	0.809	0.555		3.312	7.863	2.925	1.061	0.677	0.477	0.616
31	0.417		0.751	0.554		3.294		2.682		0.659	0.463	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	12.378	15.929	32.145	18.529	67.726	93.738	152.659	155.445	50.698	27.295	17.078	15.499
TOTAL FLOW (cms days)	0.351	0.451	0.910	0.525	1.918	2.655	4.323	4.402	1.436	0.773	0.484	0.439
TOTAL DEPTH (in)	0.316	0.407	0.822	0.474	1.731	2.396	3.903	3.974	1.296	0.698	0.437	0.396
TOTAL DEPTH (cm)	0.804	1.034	2.087	1.203	4.398	6.087	9.913	10.094	3.292	1.772	1.109	1.006

ANNUAL SUMMARY:
Sum of Mean Daily Flow 659.119 cfs = 18.666 cms
Total Depth 16.851 in = 42.801 cm
Maximum Instantaneous Flow 11.070 cfs = 0.314 cms on February 22 at 1.17 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 13
WATERSHED AREA: 540 ACRES (218 HECTARES)

WATER YEAR 1968
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.465	0.349	0.309	0.315	0.319	0.909	1.145*	1.160	0.793	0.684	0.483	0.378
2	0.592	0.347	0.312	0.298	0.330	0.923	1.068	1.243	0.775	0.672	0.484	0.464
3	0.636	0.345	0.317	0.305	0.346	0.942	1.007	1.279	0.781	0.665	0.473	0.384
4	0.417	0.345	0.328	0.310	0.364	1.015	0.988	1.293	0.785	0.655	0.467	0.382
5	0.401	0.344	0.334	0.305	0.414	1.182	0.994	1.288	0.772	0.652	0.466	0.371
6	0.392	0.343	0.312	0.299	0.472	1.218	0.943	1.251	0.756	0.647	0.454	0.368
7	0.377	0.343	0.307	0.298	0.491	1.096	0.916	1.205	0.771	0.636	0.448	0.359
8	0.369	0.341	0.304	0.303	0.472	0.973	0.877	1.156	0.762	0.631	0.443	0.350
9	0.365	0.355	0.304	0.316	0.443	0.876	0.861	1.117	0.747	0.611	0.439	0.340
10	0.363	0.381	0.307	0.341	0.426	0.796	0.911	1.088	0.744	0.616	0.442	0.330
11	0.371	0.406	0.303	0.308	0.419	0.737	1.140	1.063	0.752	0.612	0.438	0.330
12	0.418	0.363	0.290	0.307	0.408	0.708	1.171	1.053	0.730	0.626	0.432	0.349
13	0.375	0.348	0.293*	0.305	0.409	0.676	1.097	1.058	0.747	0.643	0.450	0.339
14	0.369	0.346	0.294*	0.308	0.406	0.643	1.034	1.061	0.732	0.625	0.505	0.396
15	0.361	0.357	0.295*	0.331	0.399	0.621	0.979	1.070	0.719	0.620	0.547	0.413
16	0.352	0.343	0.297*	0.338	0.386	0.613	0.922	1.039	0.718	0.599	0.470	0.383
17	0.347	0.337	0.298*	0.318	0.361	0.601	0.876	1.004	0.702	0.598	0.490	0.366
18	0.343	0.332	0.299*	0.314	0.371	0.567	0.835	0.974	0.695	0.586	0.540	0.355
19	0.340	0.327	0.300*	0.317	0.607	0.554	0.822	0.947	0.699	0.571	0.509	0.353*
20	0.340	0.325	0.302*	0.314	1.081	0.591*	0.803	0.967	0.704	0.561	0.513	0.391
21	0.383	0.322	0.303*	0.317	1.338	0.637*	0.793	0.959	0.695	0.550	0.486	0.413
22	0.408	0.319	0.305*	0.322	1.264	0.627*	0.762	0.953	0.726	0.549	0.457	0.408
23	0.355	0.319	0.308*	0.327	1.244	0.621*	0.757	0.935	0.730	0.505	0.443	0.384
24	0.343	0.330	0.313	0.340	1.338	0.614*	0.767	0.912	0.702	0.491	0.420	0.376
25	0.349	0.316	0.362	0.349	1.212	0.642*	0.780	0.914	0.700	0.485	0.403	0.372
26	0.345	0.307	0.495	0.349	1.051	0.727*	0.783	0.901	0.691	0.479	0.407	0.345
27	0.366	0.328	0.446	0.348	0.923	0.802*	0.787	0.884	0.688	0.471	0.406	0.337
28	0.513	0.323	0.399	0.348	0.857	0.815*	0.806	0.857	0.685	0.458	0.406	0.348
29	0.391	0.325	0.376	0.348	0.865	0.818*	0.910	0.838	0.694	0.478	0.399	0.337
30	0.369	0.319	0.356	0.340		0.889*	1.051	0.840	0.688	0.486	0.384	0.325
31	0.359		0.340	0.330		1.029*		0.806		0.487	0.384	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	12.175	10.185	10.109	9.969	19.017	24.462	27.583	32.114	21.885	17.947	14.086	11.044
TOTAL FLOW (cms days)	0.345	0.288	0.286	0.282	0.539	0.693	0.781	0.909	0.620	0.508	0.399	0.313
TOTAL DEPTH (in)	0.537	0.449	0.446	0.439	0.838	1.078	1.216	1.415	0.965	0.791	0.621	0.487
TOTAL DEPTH (cm)	1.363	1.140	1.132	1.116	2.129	2.739	3.088	3.595	2.450	2.009	1.577	1.236

ANNUAL SUMMARY:
Sum of Mean Daily Flow 210.576 cfs = 5.964 cms
Total Depth 9.282 in = 23.575 cm
Maximum Instantaneous Flow 1.393 cfs = 0.039 cms on February 21 at 24.00 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 13
WATERSHED AREA: 540 ACRES (218 HECTARES)

WATER YEAR 1969
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.319	0.319	0.322	0.321	0.483	0.390	1.929	1.708	1.400	0.799	0.492	0.379
2	0.318	0.317	0.321	0.320	0.469	0.415	2.081	1.626	1.371	0.779	0.485	0.379
3	0.308	0.320	0.319	0.314	0.448	0.453	2.218	1.564	1.349	0.778	0.479	0.391
4	0.308	0.330	0.319	0.316	0.428	0.503	1.949	1.526	1.317	0.762	0.483	0.390
5	0.312	0.319	0.323	0.363	0.426	0.551	2.307	1.506	1.322	0.749	0.485	0.394
6	0.307	0.314	0.316	0.480	0.413	0.553	2.689	1.516	1.275	0.740	0.469	0.393
7	0.306	0.318	0.312	0.640	0.403	0.511	2.303	1.550	1.245	0.725	0.478	0.377
8	0.305	0.333	0.313	0.565	0.384	0.474	1.968	1.585	1.262	0.706	0.471	0.366
9	0.294	0.423	0.313	0.484	0.366*	0.458	1.981	1.614	1.269	0.687	0.464	0.366
10	0.289	0.361	0.338	0.448	0.357	0.448	2.265	1.627	1.242	0.675	0.458	0.372
11	0.306	0.367	0.373	0.425	0.358	0.452	2.239	1.641	1.180	0.677	0.474	0.407
12	0.452	0.699	0.354	0.405	0.369	0.448	2.306	1.776	1.156	0.668	0.465	0.414
13	0.401	0.457	0.364	0.679	0.360	0.460	2.525	1.843	1.124	0.657	0.458	0.391
14	0.360	0.387	0.343	1.156	0.352*	0.470	2.409	1.859	1.094	0.648	0.446	0.379
15	0.351	0.366	0.339	0.950	0.355	0.496	2.210	1.895	1.077	0.635	0.432	0.377
16	0.350	0.348	0.342	0.710	0.356	0.523	2.041	1.897	1.052	0.621	0.425	0.374
17	0.347	0.336	0.321	0.603	0.357	0.570	2.126	1.948	1.030	0.606	0.421	0.372
18	0.348	0.341	0.322	0.547	0.365	0.626	2.347	1.986	1.005	0.595	0.412	0.376
19	0.347	0.349	0.335	0.524	0.375	0.618	2.258	2.041	0.999	0.596	0.410	0.453
20	0.350	0.352	0.349	0.494	0.391	0.594	2.097	2.028	1.006	0.585	0.411	0.498
21	0.344	0.369	0.340	0.817	0.425	0.624	2.078	1.956	0.962	0.572	0.405	0.423
22	0.335	0.476	0.331	0.954	0.433	0.723	2.437	1.910	0.953	0.561	0.401	0.393
23	0.332	0.431	0.340	0.777	0.431	0.721	2.808	1.864	0.996	0.546	0.401	0.397
24	0.326	0.394	0.355	0.686	0.418	0.676	2.869	1.808	0.964	0.541	0.389	0.405
25	0.323	0.370	0.338	0.607*	0.409	0.671	2.597	1.754	0.931	0.535	0.382	0.380
26	0.317	0.350	0.327	0.606*	0.394	0.771	2.317	1.703	0.927	0.520	0.390	0.372
27	0.317	0.342	0.325	0.548	0.384	0.993	2.093	1.661	0.957*	0.522	0.393	0.379
28	0.317	0.334	0.322	0.516	0.381	1.076	1.951*	1.619*	0.898	0.516	0.395	0.373
29	0.312	0.332	0.314	0.495		1.272	1.880	1.546	0.857	0.511	0.393	0.369
30	0.329	0.335	0.310	0.489		1.528	1.783	1.484	0.825	0.505	0.388	0.384
31	0.322		0.309	0.488		1.829		1.435		0.498	0.383	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	10.250	11.090	10.248	17.728	11.088	20.897	67.064	53.475	33.045	19.516	13.438	11.722
TOTAL FLOW (cms days)	0.290	0.314	0.290	0.502	0.314	0.592	1.899	1.514	0.936	0.553	0.381	0.332
TOTAL DEPTH (in)	0.452	0.489	0.452	0.781	0.489	0.921	2.956	2.357	1.457	0.860	0.592	0.517
TOTAL DEPTH (cm)	1.148	1.242	1.147	1.985	1.241	2.340	7.508	5.987	3.700	2.185	1.504	1.312

ANNUAL SUMMARY:
Sum of Mean Daily Flow 279.562 cfs = 7.917 cms
Total Depth 12.322 in = 31.299 cm
Maximum Instantaneous Flow 2.979 cfs = 0.084 cms on April 23 at 23.00 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 13
WATERSHED AREA: 540 ACRES (218 HECTARES)

WATER YEAR 1970
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.369	0.337	0.327	0.267*	0.565*	0.548	0.733*	0.512	2.178	1.673	0.740	0.476
2	0.413	0.334	0.327	0.266*	0.555*	0.579	0.720*	0.581	2.311*	1.532	0.725	0.472
3	0.377	0.331	0.327	0.265*	0.548*	0.543	0.706*	0.929	2.437*	1.421	0.714	0.466
4	0.375	0.328	0.327	0.265*	0.548*	0.575*	0.693*	1.565	2.345*	1.352	0.701	0.594
5	0.369	0.353	0.304	0.265*	0.547*	0.619*	0.679*	2.239	2.257*	1.302	0.709	0.518
6	0.365	0.355	0.292	0.265*	0.545*	0.608*	0.797	2.664	2.175*	1.281	0.685	0.491
7	0.359	0.346	0.289	0.264*	0.545*	0.669*	0.929	2.832	2.096*	1.225	0.668	0.712
8	0.382	0.335	0.293	0.262*	0.544*	0.768*	0.805	2.411	2.249*	1.174	0.663	0.614
9	0.394	0.330	0.294	0.262*	0.488	0.825*	0.768	2.205	2.442*	1.136	0.653	0.484
10	0.382	0.326	0.293	0.262*	0.454	0.872*	0.896	2.063	2.396*	1.134	0.644	0.468
11	0.373	0.325	0.295	0.264*	0.491	0.883*	1.090	1.834	2.307*	1.098	0.623	0.457
12	0.358	0.323	0.372	0.266*	0.571	0.866*	1.014	1.669	2.222*	1.060	0.597	0.452
13	0.356	0.322	0.355	0.270*	0.734	0.850*	0.883	1.518	2.138*	1.051	0.586	0.457
14	0.355	0.322	0.329	0.313*	0.703	0.850*	0.814	1.420	2.103*	1.020	0.574	0.458
15	0.353	0.321	0.317	0.353*	0.624	0.903*	0.740	1.382	2.072*	0.994	0.565	0.452
16	0.355	0.317	0.297	0.353*	0.582	0.967*	0.661	1.690	1.994*	0.974	0.555	0.446*
17	0.355	0.313	0.294	0.357*	0.639	0.979*	0.627	2.325	1.921*	0.966	0.542	0.440*
18	0.350	0.310	0.298	0.429*	0.606	0.960*	0.613	2.940	1.669	0.946	0.535	0.436
19	0.345	0.307	0.314	0.586*	0.559	0.941*	0.614	3.062	1.434	0.927	0.528	0.522
20	0.343	0.304	0.360	0.724*	0.524	0.923*	0.637	2.847	1.398	0.909	0.522	0.488
21	0.342	0.304	0.599	0.773*	0.503	0.904*	0.647	2.529	1.369	0.900	0.520	0.467
22	0.339	0.304	0.466	0.851*	0.482	0.888*	0.643	2.343	1.308	0.887	0.518	0.449
23	0.337	0.304	0.356	1.178*	0.471	0.872*	0.629	2.641	1.282	0.868	0.511	0.449
24	0.334	0.304	0.316	1.576	0.458	0.854*	0.609	2.542	1.323	0.853	0.505	0.428
25	0.335	0.304	0.296	1.094	0.447	0.838*	0.591	2.525	1.608	0.847	0.500	0.421
26	0.335	0.303	0.291	0.735	0.446	0.822*	0.575	2.531	1.660	0.841	0.495	0.413
27	0.340	0.308	0.274	0.744	0.452	0.806*	0.562	2.539	1.560	0.821	0.488	0.408
28	0.359	0.316	0.269	0.681	0.463	0.792*	0.551	2.426	1.507	0.810	0.484	0.404
29	0.346	0.321	0.267*	0.553		0.776*	0.534	2.427	1.832	0.792	0.480	0.396
30	0.341	0.325	0.267*	0.473		0.761*	0.522	2.413	1.882	0.773	0.478	0.330
31	0.340		0.267*	0.506*		0.747*		2.305		0.756	0.476	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	11.075	9.632	9.973	15.722	15.095	24.787	21.281	65.910	57.471	32.322	17.986	14.069
TOTAL FLOW (cms days)	0.314	0.273	0.282	0.445	0.427	0.702	0.603	1.867	1.628	0.915	0.509	0.398
TOTAL DEPTH (in)	0.488	0.425	0.440	0.693	0.665	1.093	0.938	2.905	2.533	1.425	0.793	0.620
TOTAL DEPTH (cm)	1.240	1.078	1.117	1.760	1.690	2.775	2.382	7.379	6.434	3.619	2.014	1.575

ANNUAL SUMMARY:
Sum of Mean Daily Flow 295.321 cfs = 8.363 cms
Total Depth 13.017 in = 33.063 cm
Maximum Instantaneous Flow 3.419 cfs = 0.097 cms on May 19 at 21.25 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 13
WATERSHED AREA: 540 ACRES (218 HECTARES)

WATER YEAR 1971
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.387	0.362	0.429	0.436*	1.626*	1.001*	2.130*	3.926*	0.000	-----	0.869	0.545
2	0.385	0.359	0.442	0.436*	1.940*	0.982*	2.074*	4.135*	0.000	-----	0.862	0.552
3	0.381	0.359	0.432	0.434*	1.758*	0.964*	2.028*	4.107*	0.000	-----	0.850	0.555
4	0.377	0.364	0.422	0.433*	1.593*	0.945*	2.050*	4.076*	-----	-----	0.799	0.539
5	0.383	0.386	0.420	0.433*	1.485*	0.926*	2.120*	4.046*	-----	-----	0.790	0.522
6	0.394	0.422	0.486	0.651*	1.431*	0.908*	2.262*	4.015*	-----	-----	0.783	0.521
7	0.400	0.430	0.577	0.861*	1.380*	0.892*	2.607*	3.988*	-----	1.495	0.768	0.520
8	0.393	0.411	0.749	0.845*	1.330*	0.875*	2.889*	3.961*	-----	1.430	0.744	0.504
9	0.396	0.428	0.647	0.829*	1.280*	0.857*	2.919*	3.930*	-----	1.385	0.725	0.493
10	0.430	0.425	0.574	0.813*	1.231*	0.841*	2.999*	3.900*	-----	1.364	0.711	0.486
11	0.400	0.412	0.534	0.797*	1.185*	0.825*	3.007*	3.870*	-----	1.322	0.706	0.479
12	0.384	0.413	0.543	0.781*	1.141*	0.809*	2.772*	3.840*	-----	1.289	0.698	0.476
13	0.374	0.399	0.553	0.768*	1.099*	0.795*	2.507*	3.810*	-----	1.260	0.684	0.472
14	0.375	0.389	0.485*	0.754*	1.064*	0.780*	2.460*	3.783*	-----	1.231	0.677	0.472
15	0.372	0.383	0.473*	0.740*	1.146*	0.764*	2.813*	3.753*	-----	1.204	0.662	0.471
16	0.372	0.388	0.450*	0.726*	1.309*	0.750*	3.135*	3.723*	-----	1.178	0.648	0.470
17	0.359	0.381	0.449*	0.711*	1.384*	0.735*	3.110*	3.697*	-----	1.146	0.640	0.468
18	0.358	0.377	0.447*	0.696*	1.368*	0.720*	2.925*	3.667*	-----	1.120	0.633	0.467
19	0.357	0.372	0.447*	0.854*	1.317*	0.706*	2.746*	3.718	-----	1.140	0.625	0.462
20	0.357	0.370	0.447*	1.594*	1.268*	0.693*	2.743*	3.621	-----	1.119	0.613	0.458
21	0.368	0.358	0.446*	2.068*	1.221*	0.715*	2.965*	3.215	-----	1.130	0.601	0.455
22	0.383	0.372	0.444*	1.872*	1.177*	0.773*	3.214*	2.882	-----	1.110	0.594	0.446
23	0.381	0.367	0.444*	1.694*	1.133*	0.856*	3.333*	2.692	-----	1.042	0.597	0.439
24	0.439	0.635	0.443*	1.536*	1.101*	1.056*	3.416*	2.585	-----	1.012	0.587	0.432
25	0.387	0.670	0.441*	1.433*	1.080*	1.362*	3.387*	2.577	-----	0.988	0.575	0.445
26	0.378	0.500	0.441*	1.380*	1.059*	1.794*	3.178*	2.706	-----	0.962	0.569	0.466
27	0.365	0.451	0.441*	1.330*	1.039*	2.319*	2.968*	2.994	-----	0.945	0.559	0.459
28	0.364	0.435	0.440*	1.280*	1.020*	2.383*	2.933*	3.480	-----	0.919	0.553	0.451
29	0.369	0.414	0.439*	1.233*		2.106*	3.099*	3.940	-----	0.901	0.551	0.507
30	0.369	0.435	0.439*	1.189*		2.040*	3.471*	4.405	-----	0.889	0.546	0.462
31	0.367		0.437*	1.191*		2.103*		4.418		0.871	0.550	

MONTHLY SUMMARY:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	11.806	12.463	14.864	30.796	36.165	34.278	84.259	113.459	0.000	28.453	20.770	14.493
TOTAL FLOW (cms days)	0.334	0.353	0.421	0.872	1.024	0.971	2.386	3.213	0.000	0.806	0.588	0.410
TOTAL DEPTH (in)	0.520	0.549	0.655	1.357	1.594	1.511	3.714	5.001	0.000	1.254	0.915	0.639
TOTAL DEPTH (cm)	1.322	1.395	1.664	3.448	4.049	3.838	9.433	12.702	0.000	3.185	2.325	1.623

ANNUAL SUMMARY:
Sum of Mean Daily Flow 401.806 cfs = 11.379 cms
Total Depth 17.710 in = 44.985 cm
Maximum Instantaneous Flow 4.727 cfs = 0.134 cms on May 30 at 9.00 hours

* Indicates some data were estimated during this day.
Summaries exclude missing data.

TAILHOLT CREEK STUDY AREA
WATERSHED: 13
WATERSHED AREA: 540 ACRES (218 HECTARES)

WATER YEAR 1972
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.459	0.406	0.380	0.392*	0.299	1.309	0.740	1.558	3.338	1.285	0.657	0.434
2	0.446	0.400	0.398	0.391*	0.303	0.913	0.809	1.593	3.445	1.255	0.620	0.428
3	0.427	0.406	0.386	0.391*	0.306	0.772	0.930	1.839	3.481	1.216	0.609	0.424
4	0.428	0.407	0.377	0.392*	0.307	0.679	0.994	2.494	3.378	1.177	0.589	0.420
5	0.448	0.387	0.390	0.391*	0.307	0.638	1.104	2.923	3.250	1.151	0.579	0.424
6	0.447	0.385	0.396	0.389*	0.307	0.736	1.475	3.353	3.122	1.139	0.578	0.445
7	0.431	0.398	0.380	0.385*	0.304	0.978	1.478	3.343	3.019	1.107	0.561	0.435
8	0.422	0.389	0.380	0.385*	0.299	0.913	1.341	3.203	2.955	1.081	0.554	0.424
9	0.423	0.389	0.380	0.387*	0.295	0.963	1.212	2.891	2.812	1.111	0.548	0.415
10	0.419	0.396	0.363	0.386*	0.288	1.705	1.128	2.636	2.780	1.075	0.549	0.409
11	0.414	0.392	0.350	0.386*	0.284	2.060	1.109	2.405	2.622	1.030	0.545	0.413
12	0.414	0.417	0.355	0.384*	0.277	1.807	1.119	2.364	2.468	0.990	0.532	0.423
13	0.400	0.390	0.352	0.382*	0.266	1.974	1.070	2.541	2.362	0.963	0.530	0.423
14	0.410	0.378	0.357	0.381*	0.252	2.070	1.039	3.052	2.275	0.934	0.539	0.417
15	0.420	0.374	0.354	0.379*	0.246	1.695	1.021	3.661	2.192	0.909	0.567	0.410
16	0.420	0.367	0.355	0.377*	0.248	1.738	1.070	3.877	2.138	0.886	0.542	0.400
17	0.417	0.366	0.363	0.376*	0.251	1.975	1.081	3.743	2.049	0.858	0.525	0.391
18	0.414	0.363	0.359	0.376*	0.290	2.099	1.049	3.618	1.967	0.838	0.528	0.385
19	0.442	0.367	0.352	0.375*	0.353	1.815	0.998	3.330	1.895	0.875	0.528	0.379
20	0.464	0.369	0.348	0.407	0.507	1.470	0.973	3.059	1.842	0.855	0.513	0.376
21	0.436	0.367	0.347	0.552	0.574	1.339	0.979	2.855	1.784	0.854	0.503	0.373
22	0.412	0.369	0.410	0.401	0.605	1.429	0.948	2.822	1.715	0.810	0.501	0.369
23	0.399	0.363	0.384	0.344	0.552	1.747	0.942	2.858	1.666	0.769	0.506	0.371
24	0.397	0.372	0.347	0.313	0.453	1.485	1.062	2.765	1.606	0.740	0.498	0.372
25	0.393	0.369	0.374	0.307	0.387	1.270	1.097	2.607	1.585	0.713	0.489	0.377
26	0.395	0.374	0.345	0.298	0.350	1.082	1.064	2.485	1.529	0.690	0.477	0.375
27	0.405	0.402	0.330	0.296	0.590	0.971	1.231	2.434	1.463	0.674	0.466	0.374
28	0.400	0.399	0.413	0.297	1.504	0.871	1.806	2.490	1.406	0.654	0.458	0.373
29	0.397	0.399	0.386	0.296	2.838	0.812	2.183	2.636	1.356	0.640	0.464	0.369
30	0.408	0.394	0.392	0.297		0.768	1.773	2.849	1.319	0.626	0.455	0.366
31	0.407		0.393	0.298		0.732		3.093		0.669	0.442	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	13.014	11.554	11.497	11.412	13.842	40.815	34.828	87.373	68.817	28.572	16.455	11.994
TOTAL FLOW (cms days)	0.369	0.327	0.326	0.323	0.392	1.156	0.986	2.474	1.949	0.809	0.466	0.340
TOTAL DEPTH (in)	0.574	0.509	0.507	0.503	0.610	1.799	1.535	3.851	3.033	1.259	0.725	0.529
TOTAL DEPTH (cm)	1.457	1.294	1.287	1.278	1.550	4.570	3.899	9.782	7.704	3.199	1.842	1.343

ANNUAL SUMMARY:
Sum of Mean Daily Flow 350.173 cfs = 9.917 cms
Total Depth 15.435 in = 39.204 cm
Maximum Instantaneous Flow 3.915 cfs = 0.111 cms on May 16 at 17.86 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 13
WATERSHED AREA: 540 ACRES (218 HECTARES)

WATER YEAR 1973
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.362	0.336	0.340	0.324*	0.310*	0.300	0.322	0.711	0.465	0.324	0.300	0.298
2	0.358	0.339	0.342	0.324*	0.309*	0.258	0.314	0.697	0.456	0.320	0.302	0.285
3	0.354	0.336	0.332	0.324*	0.309*	0.228	0.315	0.738	0.457	0.318	0.317	0.273
4	0.351	0.357	0.327*	0.324*	0.309*	0.217	0.335	0.818	0.442	0.316	0.307	0.268
5	0.303	0.360	0.329*	0.323*	0.307*	0.221	0.390	0.796	0.432	0.319	0.295	0.265
6	0.284	0.338	0.329*	0.321*	0.306*	0.218	0.395	0.790	0.422	0.321	0.296	0.262
7	0.282	0.339	0.330*	0.322*	0.307*	0.217	0.371	0.784	0.412	0.318	0.293	0.295
8	0.279	0.346	0.331*	0.320*	0.308*	0.223	0.361	0.855	0.403	0.315	0.289	0.302
9	0.292	0.342	0.332*	0.319*	0.307*	0.238	0.371	0.803	0.405	0.309	0.289	0.285
10	0.327	0.341	0.332*	0.319*	0.308*	0.284	0.395	0.785	0.396	0.301	0.294	0.276
11	0.341	0.340	0.330*	0.318*	0.308*	0.283	0.434	0.762	0.390	0.296	0.291	0.268
12	0.294	0.341	0.331*	0.317*	0.307*	0.287	0.498	0.735	0.387	0.297	0.287	0.265
13	0.294	0.344	0.333*	0.317*	0.306*	0.291	0.579	0.707	0.402	0.300	0.276	0.260
14	0.312	0.359	0.334*	0.316*	0.305*	0.289	0.589	0.678	0.568	0.299	0.280	0.291
15	0.308	0.357	0.333*	0.316*	0.305*	0.283	0.545	0.653	0.432	0.293	0.278	0.291
16	0.303	0.354	0.334*	0.318*	0.303*	0.290	0.559	0.639	0.412	0.289	0.276	0.277
17	0.303	0.353	0.334*	0.318*	0.299*	0.334	0.604	0.625	0.477	0.287	0.274	0.269
18	0.293	0.357	0.332*	0.317*	0.295*	0.309	0.528	0.612	0.427	0.289	0.275	0.268
19	0.298	0.354	0.331*	0.315*	0.292*	0.312	0.482	0.617	0.392	0.335	0.274	0.308
20	0.304	0.345	0.330*	0.315*	0.291*	0.316	0.453	0.610	0.368	0.414	0.271	0.339
21	0.302	0.336	0.326*	0.315*	0.288*	0.341	0.442	0.591	0.357	0.363	0.280	0.299
22	0.304	0.328*	0.322*	0.315*	0.284*	0.348	0.441	0.574	0.349	0.347	0.282	0.286
23	0.307	0.328*	0.323*	0.315*	0.283*	0.348	0.500	0.560	0.347	0.329	0.281	0.297
24	0.315	0.329*	0.323*	0.314*	0.280*	0.351	0.542	0.578	0.342	0.321	0.277	0.316
25	0.311	0.330*	0.324*	0.315*	0.277*	0.385	0.591	0.608	0.345	0.317	0.293	0.303
26	0.314	0.331*	0.326*	0.317*	0.276*	0.428	0.645	0.547	0.339	0.314	0.290	0.285
27	0.321	0.331*	0.327*	0.319*	0.275*	0.397	0.740	0.524	0.331	0.314	0.278	0.281
28	0.324	0.331*	0.326*	0.318*	0.276*	0.371	0.770	0.505	0.327	0.310	0.271	0.276
29	0.325	0.334	0.325*	0.316*		0.350	0.746	0.494	0.333	0.308	0.268	0.273
30	0.326	0.334	0.324*	0.312*		0.337	0.732	0.475	0.331	0.304	0.264	0.272
31	0.327		0.324*	0.312*		0.337		0.481		0.300	0.290	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	9.718	10.251	10.216	9.859	8.333	9.392	14.989	20.353	11.946	9.788	8.838	8.534
TOTAL FLOW (cms days)	0.275	0.290	0.289	0.279	0.236	0.266	0.424	0.576	0.338	0.277	0.250	0.242
TOTAL DEPTH (in)	0.428	0.452	0.450	0.435	0.367	0.414	0.661	0.897	0.527	0.431	0.390	0.376
TOTAL DEPTH (cm)	1.088	1.148	1.144	1.104	0.933	1.051	1.678	2.279	1.337	1.096	0.989	0.955

ANNUAL SUMMARY:
Sum of Mean Daily Flow 132.215 cfs = 3.744 cms
Total Depth 5.828 in = 14.802 cm
Maximum Instantaneous Flow 0.996 cfs = 0.028 cms on May 8 at 6.01 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 13
WATERSHED AREA: 540 ACRES (218 HECTARES)

WATER YEAR 1974
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.277	0.329	0.501	0.410*	0.570	0.850*	1.901*	3.204	4.646	2.652	0.942	0.570
2	0.271	0.293	0.526	0.410*	0.533	0.831*	1.714*	3.390	4.665	2.515	0.931	0.561
3	0.273	0.288	0.496	0.411*	0.517	0.761*	1.587*	3.411	4.930	2.417	0.918	0.551
4	0.270	0.292	0.463	0.412*	0.512	0.715*	1.421*	3.568	5.382	2.352	0.894	0.536
5	0.268	0.314	0.439	0.413*	0.477	0.677*	1.396*	4.221	5.567	2.274	0.868	0.535
6	0.265	0.480	0.429	0.415*	0.457	0.636*	1.313*	4.912	5.508	2.179	0.916	0.528
7	0.296	0.354	0.526	0.415*	0.452	0.609*	1.297*	4.814	5.325	2.109	0.873	0.517
8	0.277	0.391	0.579	0.416*	0.448	0.579*	1.355*	5.146	4.981	2.042	0.840	0.505
9	0.269	0.492	0.559	0.418*	0.441	0.569*	1.350*	5.599	4.648	2.016	0.798	0.507
10	0.270	0.924	0.529	0.421*	0.439	0.579*	1.329*	4.855	4.382	1.988	0.778	0.517
11	0.269	0.970	0.504	0.422*	0.442	0.622*	1.316*	4.065	4.310	1.882	0.759	0.522
12	0.268	1.544	0.468	0.425*	0.445	0.690*	1.301*	3.682	4.447	1.751	0.742	0.529
13	0.268	0.927	0.451	0.428*	0.451	0.717*	1.224	3.349	4.744	1.658	0.730	0.512
14	0.278	0.634	0.429	0.454*	0.451	0.729*	1.252	3.064	5.003	1.589	0.798	0.492
15	0.272	0.585	0.413	0.841*	0.451	0.805*	1.453	2.823	5.199	1.538	0.729	0.482
16	0.270	0.709	0.425	3.394*	0.443*	1.315*	1.808	2.607	5.326	1.450	0.708	0.478
17	0.266	0.803	0.582	3.757	0.436*	1.665*	2.159	2.481	5.347	1.369	0.698	0.467
18	0.263	0.685	0.696	1.580	0.444*	1.588*	2.576	2.362	5.286	1.318	0.694	0.454
19	0.261	0.565	0.664	1.475	0.442*	1.428*	2.892	2.303	5.126	1.275	0.731	0.453
20	0.264	0.491	0.609	1.561	0.444*	1.301*	2.595	2.345	5.072	1.238	0.824	0.450
21	0.266	0.457	0.593	1.709	0.453*	1.189*	2.335	2.295	4.748	1.214	0.715	0.446
22	0.261	0.431	0.568	1.326	0.441*	1.085*	2.618	2.325	4.465	1.137	0.693	0.435
23	0.271	0.411	0.545	1.085	0.438*	1.016*	3.512	2.540	4.172	1.095	0.666	0.425
24	0.286	0.390	0.519	0.955	0.440*	0.981*	4.680	2.909	3.871	1.074	0.654	0.421
25	0.317	0.382	0.501	0.878	0.440*	1.009*	5.378	3.372	3.660	1.058	0.639	0.413
26	0.285	0.373	0.473	0.793	0.436*	1.115*	5.012	4.149	3.445	1.045	0.627	0.429
27	0.284	0.364	0.473	0.712	0.439*	1.417*	3.747	5.392	3.245	1.071	0.615	0.447
28	0.283	0.371	0.464	0.666	0.624*	1.480*	3.021	5.914	3.062	1.030	0.608	0.430
29	0.285	0.398	0.445	0.620		1.966*	2.612	5.792	2.903	1.014	0.602	0.415
30	0.285	0.427	0.426	0.589		2.325*	2.647	5.345	2.758	0.996	0.590	0.401
31	0.370		0.413*	0.588		2.180*		4.913		0.966	0.576	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	8.608	16.073	15.711	28.400	13.003	33.428	68.801	117.147	136.223	49.313	23.154	14.427
TOTAL FLOW (cms days)	0.244	0.455	0.445	0.804	0.368	0.947	1.948	3.318	3.858	1.397	0.656	0.409
TOTAL DEPTH (in)	0.379	0.708	0.692	1.252	0.573	1.473	3.033	5.163	6.004	2.174	1.021	0.636
TOTAL DEPTH (cm)	0.964	1.799	1.759	3.180	1.456	3.742	7.703	13.115	15.251	5.521	2.592	1.615

ANNUAL SUMMARY:
Sum of Mean Daily Flow 524.287 cfs = 14.848 cms
Total Depth 23.109 in = 58.697 cm
Maximum Instantaneous Flow 6.010 cfs = 0.170 cms on May 28 at 18.33 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 13
WATERSHED AREA: 540 ACRES (218 HECTARES)

WATER YEAR 1975
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.385	0.383	0.338*	0.326*	0.289*	0.272*	0.309*	0.558	1.661*	1.231	0.765	0.555*
2	0.384	0.376	0.338*	0.331*	0.289*	0.275*	0.313*	0.588	1.861*	1.212	0.746	0.560*
3	0.379	0.371	0.340*	0.332*	0.289*	0.277*	0.338*	0.862	1.907*	1.184	0.731	0.540*
4	0.371	0.370	0.353*	0.330*	0.290*	0.281*	0.354*	0.956	1.897*	1.172	0.722	0.528*
5	0.379	0.371	0.348*	0.321*	0.290*	0.284*	0.362*	0.789	1.908*	1.152	0.705	0.521*
6	0.376	0.371	0.343*	0.320*	0.288*	0.291*	0.367*	0.743	1.963*	1.150	0.691	0.515*
7	0.368	0.413	0.343*	0.312*	0.285*	0.297*	0.372*	0.819	2.030*	1.129	0.741	0.502*
8	0.366	0.402	0.332*	0.312*	0.284*	0.330*	0.374*	0.973*	2.070*	1.108	0.686	0.499*
9	0.368	0.375	0.333*	0.295*	0.282*	0.354*	0.380*	1.154*	2.075*	1.093	0.674	0.499*
10	0.366	0.380	0.333*	0.296*	0.281*	0.348*	0.389*	1.349*	2.046*	1.075	0.661	0.496*
11	0.366	0.373	0.335*	0.299*	0.280*	0.330*	0.410*	1.531*	1.992*	1.064	0.648	0.490*
12	0.375	0.373	0.333*	0.299*	0.279*	0.315*	0.451*	1.511*	1.926*	1.072	0.640	0.512
13	0.377	0.369	0.333*	0.311*	0.279*	0.310*	0.492*	1.665*	1.873*	1.068	0.624	0.508
14	0.376	0.366	0.330*	0.317*	0.279*	0.305*	0.520*	1.972*	1.833*	1.030	0.621	0.502
15	0.375	0.367	0.330*	0.313*	0.278*	0.308*	0.552*	2.430*	1.811*	1.020	0.618	0.500
16	0.369	0.362	0.332*	0.303*	0.277*	0.315*	0.570*	2.465*	1.781*	1.017	0.602	0.493
17	0.376	0.363	0.334*	0.306*	0.276*	0.311*	0.580*	2.199*	1.811*	1.006	0.622	0.494
18	0.390	0.396	0.321*	0.323*	0.275*	0.342*	0.588*	2.007*	1.770*	1.000	0.665	0.491
19	0.400	0.373	0.322*	0.295*	0.274*	0.345*	0.591*	1.845*	1.758*	0.976	0.767	0.480
20	0.413	0.369	0.325*	0.292*	0.272*	0.347*	0.610*	1.709*	1.710*	0.949	0.705	0.478
21	0.425	0.383	0.339*	0.277*	0.271*	0.345*	0.633*	1.616*	1.649*	0.928	0.628	0.472
22	0.411	0.397	0.323*	0.276*	0.269*	0.349*	0.660*	1.467*	1.603*	0.909	0.626	0.469
23	0.405	0.373*	0.320*	0.282*	0.269*	0.342*	0.680*	1.391*	1.581*	0.893	0.787	0.464
24	0.400	0.364*	0.319*	0.283*	0.269*	0.346*	0.700*	1.341*	1.573*	0.874	0.680	0.463
25	0.385	0.363*	0.320*	0.324*	0.268*	0.350*	0.765*	1.262*	1.463*	0.858	0.624	0.462
26	0.382	0.354*	0.314*	0.333*	0.267*	0.342*	0.707*	1.215*	1.415	0.843	0.597*	0.460
27	0.385	0.352*	0.323*	0.285*	0.269*	0.329*	0.635	1.195*	1.350	0.827	0.584*	0.459
28	0.392	0.350*	0.315*	0.290*	0.270*	0.323*	0.581	1.183*	1.315	0.809	0.592*	0.456
29	0.387	0.343*	0.368*	0.285*		0.315*	0.553	1.184*	1.281	0.807	0.579*	0.454
30	0.380	0.341*	0.349*	0.288*		0.307*	0.554	1.228*	1.253	0.789	0.559*	0.452
31	0.378		0.321*	0.288*		0.307*		1.429*		0.780	0.550*	

MONTHLY SUMMARY:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	11.891	11.145	10.305	9.444	7.789	9.894	15.391	42.635	52.164	31.024	20.443	14.772
TOTAL FLOW (cms days)	0.337	0.316	0.292	0.267	0.221	0.280	0.436	1.207	1.477	0.879	0.579	0.418
TOTAL DEPTH (in)	0.524	0.491	0.454	0.416	0.343	0.436	0.678	1.879	2.299	1.367	0.901	0.651
TOTAL DEPTH (cm)	1.331	1.248	1.154	1.057	0.872	1.108	1.723	4.773	5.840	3.473	2.289	1.654

ANNUAL SUMMARY:
Sum of Mean Daily Flow 236.896 cfs = 6.709 cms
Total Depth 10.442 in = 26.522 cm
Maximum Instantaneous Flow 2.644 cfs = 0.075 cms on May 15 at 16.54 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 13
WATERSHED AREA: 540 ACRES (218 HECTARES)

WATER YEAR 1976
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.456	0.406	0.418	0.435	0.443	0.389	0.489*	0.946*	1.671	0.965	0.633	0.484
2	0.451	0.412	0.538	0.454	0.453	0.370	0.489*	1.066*	1.612	0.945	0.631	0.474
3	0.444	0.428	0.584	0.447	0.464	0.362	0.498*	1.243*	1.581	0.926	0.613	0.468
4	0.441	0.406	0.928	0.363	0.461	0.365	0.565*	1.526*	1.533	0.908	0.614	0.465
5	0.440	0.387	1.096	0.345	0.459	0.367*	0.696*	1.536*	1.486	0.895	0.610	0.459
6	0.573	0.382	0.752	0.340	0.459	0.369*	0.801*	1.548*	1.455	0.874	0.595	0.520
7	0.585	0.388	0.819	0.338	0.459	0.370*	0.919*	1.587*	1.428	0.864	0.582	0.482
8	0.469	0.374	0.971	0.349	0.459	0.371*	1.118*	1.715*	1.412	0.853	0.599	0.469
9	0.454	0.369	0.927	0.347	0.422	0.373*	1.474*	1.872*	1.393	0.844	0.611	0.465
10	0.450	0.374	0.839	0.339	0.383	0.374*	1.476*	2.044*	1.454	0.829	0.596	0.459
11	0.489	0.359	0.745	0.349	0.378	0.375*	1.393*	2.421*	1.563	0.815	0.579	0.486
12	0.474	0.358	0.659	0.342	0.379	0.377*	1.393*	2.417*	1.495	0.841	0.573	0.483
13	0.462	0.365	0.579	0.335	0.373	0.378*	1.397*	2.413*	1.672	0.808	0.570	0.463
14	0.450	0.368	0.524	0.346	0.371	0.379*	1.358*	2.412*	1.594	0.782	0.561	0.451
15	0.442	0.477	0.494	0.392	0.357	0.381*	1.294*	2.408*	1.514	0.775	0.563	0.449
16	0.437	0.516	0.463	0.390	0.360	0.382*	1.181*	2.400*	1.457	0.763	0.585	0.462
17	0.432	0.448	0.440	0.394	0.358	0.383*	1.107*	2.355*	1.358	0.767	0.572	0.471
18	0.428	0.409	0.446	0.403	0.348	0.385*	1.062*	2.314*	1.272	0.949	0.560	0.466
19	0.423	0.415	0.420	0.398	0.344	0.386*	0.987*	2.289*	1.231	0.863	0.552	0.450
20	0.421	0.378	0.415	0.401	0.337	0.388*	0.953*	2.258*	1.246	0.769	0.529	0.438
21	0.565	0.366	0.404	0.400	0.335	0.389*	0.934*	2.227*	1.247	0.738	0.516	0.433
22	0.482	0.362	0.404	0.398	0.335	0.390*	0.928*	2.197*	1.160	0.710	0.534	0.517
23	0.408	0.370	0.399	0.399	0.339	0.392*	0.907*	2.176*	1.110	0.695	0.567	0.477
24	0.382	0.370	0.393	0.396	0.339	0.393*	0.902*	2.149*	1.089	0.729	0.548	0.454
25	0.393	0.350	0.383	0.390	0.344	0.394*	0.902*	2.099	1.092	0.715	0.527	0.444
26	0.500	0.357	0.410	0.383	0.391	0.396*	0.902*	1.996	1.083	0.683	0.529	0.431
27	0.434	0.359	0.381	0.380	0.395	0.397*	0.902*	1.935	1.066	0.668	0.508	0.424
28	0.412	0.344	0.367	0.385	0.398	0.399*	0.903*	1.937	1.034	0.660	0.496	0.418
29	0.417	0.362	0.383	0.389	0.394	0.397*	0.902*	1.832	1.004	0.650	0.487	0.412
30	0.440	0.377	0.374	0.401		0.400*	0.903*	1.791	0.984	0.639	0.502	0.407
31	0.421		0.355	0.422		0.440*		1.776		0.630	0.494	

MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	14.078	11.635	17.308	11.849	11.335	11.911	29.735	60.884	40.296	24.551	17.436	13.778
TOTAL FLOW (cms days)	0.399	0.330	0.490	0.336	0.321	0.337	0.842	1.724	1.141	0.695	0.494	0.390
TOTAL DEPTH (in)	0.620	0.513	0.763	0.522	0.500	0.525	1.311	2.684	1.776	1.082	0.769	0.607
TOTAL DEPTH (cm)	1.576	1.303	1.938	1.327	1.269	1.333	3.329	6.816	4.511	2.749	1.952	1.543

ANNUAL SUMMARY:
Sum of Mean Daily Flow 264.797 cfs = 7.499 cms
Total Depth 11.671 in = 29.646 cm
Maximum Instantaneous Flow 2.423 cfs = 0.069 cms on May 10 at 24.00 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 13
WATERSHED AREA: 540 ACRES (218 HECTARES)

WATER YEAR 1977
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.405	0.348	0.313	0.270	0.261	0.239	0.246	0.287	0.263*	0.226	0.196	0.194
2	0.431	0.363	0.317	0.270	0.258	0.239	0.242	0.296	0.260*	0.229	0.197	0.186
3	0.417	0.357	0.316	0.270	0.251	0.238	0.243	0.289	0.254*	0.321	0.200	0.183
4	0.408	0.353	0.316	0.270	0.249	0.235	0.284	0.287	0.248*	0.273	0.195	0.180
5	0.404	0.346	0.308	0.270	0.246	0.236	0.315	0.278	0.245*	0.248	0.199	0.181
6	0.405	0.343	0.303	0.270	0.247	0.251	0.350	0.288	0.242	0.240	0.221	0.180
7	0.400	0.340	0.319	0.270	0.246	0.280	0.407	0.283	0.248	0.233	0.205	0.181
8	0.396	0.338	0.325	0.270	0.247	0.276	0.466	0.283	0.289	0.225	0.199	0.178
9	0.394	0.338	0.310	0.270	0.249	0.293	0.434	0.275	0.260	0.229	0.194	0.181
10	0.389	0.338	0.298	0.270	0.246	0.258	0.353	0.275	0.268	0.226	0.192	0.182
11	0.389	0.338	0.299	0.270	0.246	0.250	0.334	0.263	0.281	0.219	0.190	0.182
12	0.381	0.338	0.297	0.270	0.247	0.257	0.336	0.256	0.260	0.216	0.188	0.181
13	0.376	0.336	0.298	0.270	0.247	0.256	0.339	0.249	0.256	0.216	0.184	0.179
14	0.372	0.336	0.296	0.270	0.237	0.246	0.321	0.247	0.261	0.215	0.190	0.180
15	0.370	0.335	0.307	0.270	0.230	0.239	0.312	0.249	0.258	0.212	0.190	0.243
16	0.367	0.335	0.306	0.270	0.235	0.242	0.324	0.274	0.254	0.208	0.185	0.258
17	0.362	0.333	0.301	0.270	0.232	0.240	0.313	0.291	0.249	0.206	0.186	0.261
18	0.365	0.331	0.299	0.270	0.236	0.235	0.296	0.306	0.247	0.210	0.184	0.211
19	0.371	0.328	0.298	0.270	0.232	0.237	0.292	0.302	0.246	0.235	0.186	0.207
20	0.370	0.328	0.301	0.270	0.235	0.226	0.294	0.284	0.266	0.214	0.185	0.245
21	0.367	0.327	0.327	0.270	0.248	0.231	0.296	0.269	0.265	0.215	0.184	0.250
22	0.364	0.328	0.347	0.270	0.241	0.250	0.308	0.260	0.247	0.220	0.194	0.249
23	0.363	0.328	0.370	0.270	0.239	0.269	0.317	0.280	0.238	0.216	0.186	0.235
24	0.352	0.327	0.354	0.270	0.232	0.260	0.309	0.296*	0.235	0.247	0.203	0.283
25	0.371	0.326	0.309	0.270	0.227	0.252	0.296	0.296*	0.232	0.255	0.226	0.259
26	0.367	0.316	0.284	0.270	0.227	0.249	0.286	0.279*	0.231	0.218	0.268	0.245
27	0.360	0.577	0.278	0.262	0.227	0.248	0.277	0.300*	0.228	0.211	0.236	0.224
28	0.357	0.504	0.272	0.259	0.240	0.242	0.272	0.287*	0.227	0.206	0.216	0.228
29	0.355	0.324	0.271	0.257		0.239	0.269	0.278*	0.226	0.202	0.211	0.302
30	0.354	0.311	0.267	0.258		0.244	0.266	0.271*	0.225	0.200	0.247	0.267
31	0.351		0.268	0.259		0.244		0.264*		0.199	0.213	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	11.731	10.468	9.473	8.306	6.762	7.699	9.397	8.643	7.511	6.991	6.248	6.513
TOTAL FLOW (cms days)	0.332	0.296	0.268	0.235	0.191	0.218	0.266	0.245	0.213	0.198	0.177	0.184
TOTAL DEPTH (in)	0.517	0.461	0.418	0.366	0.298	0.339	0.414	0.381	0.331	0.308	0.275	0.287
TOTAL DEPTH (cm)	1.313	1.172	1.061	0.930	0.757	0.862	1.052	0.968	0.841	0.783	0.700	0.729

ANNUAL SUMMARY:
Sum of Mean Daily Flow 99.743 cfs = 2.825 cms
Total Depth 4.396 in = 11.167 cm
Maximum Instantaneous Flow 0.870 cfs = 0.025 cms on November 27 at 13.00 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 13
WATERSHED AREA: 540 ACRES (218 HECTARES)

WATER YEAR 1978
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.236	0.225	0.238	0.226	0.248	0.577	2.713	1.863	1.334	0.993	0.534	0.353
2	0.225	0.236	0.371	0.236	0.248	0.522	2.369	1.830	1.306	0.989	0.525	0.346
3	0.212	0.224	0.409	0.237	0.260	0.497	1.965	1.770	1.278	1.048	0.519	0.337
4	0.199	0.222	0.357	0.237	0.251	0.475	1.689	1.728	1.254	1.024	0.509	0.330
5	0.201	0.230	0.304	0.238	0.265	0.479	1.482	1.667	1.238*	0.987	0.507	0.347
6	0.203	0.221	0.285	0.239	0.325	0.470	1.395	1.589	1.235*	0.944	0.496	0.384
7	0.222	0.219	0.272	0.240	0.395	0.484	1.332	1.503	1.219*	0.920	0.477	0.426
8	0.206	0.211	0.251	0.245	0.457	0.567	1.266	1.419	1.201*	0.931	0.470	0.369
9	0.202	0.210	0.242	0.247	0.481	0.787	1.202	1.368	1.191*	0.890	0.464	0.342
10	0.198	0.213	0.245	0.245	0.446	0.902	1.212	1.443	1.257*	0.866	0.472	0.365
11	0.198	0.213	0.288	0.244	0.414	0.849	1.343	1.417	1.182*	0.846	0.462	0.368
12	0.202	0.214	0.290	0.243	0.375	0.773	1.394	1.412	1.155*	0.821	0.452	0.369
13	0.202	0.217	0.441	0.238	0.349	0.689	1.380	1.465	1.130*	0.800	0.535	0.394
14	0.203	0.212	1.151	0.246	0.332	0.615	1.362	1.469	1.115*	0.775	0.521	0.418
15	0.202	0.229	2.066	0.247	0.322	0.553	1.391	1.497	1.099*	0.769	0.475	0.428
16	0.202	0.219	1.011	0.250	0.304	0.519	1.443	1.506	1.070*	0.750	0.512	0.422
17	0.202	0.208	0.607	0.265	0.318	0.544	1.398	1.510	1.052*	0.740	0.492	0.433
18	0.202	0.200	0.462	0.261	0.294	0.724	1.318	1.519	1.044*	0.729	0.467	0.452
19	0.201	0.206	0.385	0.266	0.296	0.933	1.285	1.502	1.030*	0.713	0.440	0.444
20	0.196	0.253	0.360	0.268	0.299	0.965	1.328	1.472	1.060*	0.700	0.428	0.431
21	0.197	0.190	0.321	0.269	0.325	1.125	1.326	1.438	1.166	0.684	0.420	0.419
22	0.199	0.197	0.303	0.269	0.392	1.291	1.283	1.414	1.155	0.666	0.446	0.406
23	0.197	0.204	0.302	0.253	0.478	1.369	1.255	1.433	1.131	0.643	0.434	0.397
24	0.199	0.212	0.295	0.305	0.532	1.310	1.233	1.472	1.116	0.623	0.410	0.396
25	0.275	0.279	0.280	0.269	0.637	1.169	1.254	1.485	1.157	0.608	0.398	0.392
26	0.260	0.283	0.271	0.268	0.715	1.278	1.377	1.483	1.102	0.591	0.398	0.387
27	0.227	0.246	0.254	0.255	0.718	1.624	1.677	1.466	1.071	0.586	0.389	0.377
28	0.220	0.238	0.245	0.255	0.645	1.994	1.774	1.444	1.049	0.608	0.382	0.374
29	0.219	0.248	0.250	0.256		2.257	1.800	1.414	1.025	0.581	0.375	0.379
30	0.230	0.238	0.248	0.248		2.515	1.828	1.391	1.009	0.561	0.376	0.372
31	0.228		0.237	0.247		2.572		1.366		0.545	0.369	
MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	6.565	6.717	13.040	7.810	11.122	31.426	45.077	46.755	34.432	23.932	14.155	11.657
TOTAL FLOW (cms days)	0.186	0.190	0.369	0.221	0.315	0.890	1.277	1.324	0.975	0.678	0.401	0.330
TOTAL DEPTH (in)	0.289	0.296	0.575	0.344	0.490	1.385	1.987	2.061	1.518	1.055	0.624	0.514
TOTAL DEPTH (cm)	0.735	0.752	1.460	0.874	1.245	3.518	5.047	5.234	3.855	2.679	1.585	1.305

ANNUAL SUMMARY:

Sum of Mean Daily Flow 252.689 cfs = 7.156 cms
Total Depth 11.138 in = 28.290 cm
Maximum Instantaneous Flow 2.794 cfs = 0.079 cms on April 1 at 6.00 hours

*** Indicates some data were estimated during this day.**

TAILHOLT CREEK STUDY AREA
WATERSHED: 13
WATERSHED AREA: 540 ACRES (218 HECTARES)

WATER YEAR 1979
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.372	0.294	0.296	0.295	0.294	0.294	0.491	1.270	0.604	0.441	0.355	0.297
2	0.371	0.295	0.296	0.296	0.294	0.294	0.491	1.286	0.601	0.440	0.353	0.278
3	0.369	0.295	0.294	0.297	0.295	0.294	0.491	1.262	0.592	0.461	0.350	0.272
4	0.366	0.295	0.294	0.296	0.294	0.341	0.491	1.246	0.583	0.453	0.347	0.275
5	0.364	0.295	0.294	0.296	0.294	0.439	0.491	1.241	0.590	0.442	0.342	0.275
6	0.360	0.295	0.295	0.296	0.294	0.491	0.492	1.190	0.566	0.443	0.343	0.273
7	0.357	0.295	0.294	0.296	0.295	0.491	0.491	1.121	0.539	0.437	0.341	0.271
8	0.357	0.295	0.295	0.296	0.296	0.491	0.491	1.068	0.534	0.420	0.325	0.264
9	0.352	0.295	0.296	0.294	0.295	0.490	0.491	1.004	0.517	0.414	0.299	0.266
10	0.348	0.294	0.295	0.294	0.295	0.493	0.491	0.926	0.505	0.409	0.292	0.266
11	0.345	0.295	0.295	0.296	0.294	0.491	0.491	0.870	0.495	0.410	0.294	0.265
12	0.342	0.296	0.295	0.297	0.294	0.491	0.491	0.814	0.484	0.409	0.312	0.265
13	0.339	0.295	0.296	0.296	0.294	0.492	0.491	0.785	0.477	0.406	0.349	0.262
14	0.339	0.296	0.294	0.297	0.294	0.491	0.491	0.767	0.473	0.402	0.335	0.258
15	0.341	0.295	0.294	0.296	0.294	0.492	0.491	0.756	0.468	0.396	0.305	0.256
16	0.339	0.294	0.294	0.296	0.294	0.491	0.491	0.755	0.461	0.391	0.300	0.253
17	0.343	0.296	0.294	0.297	0.294	0.491	0.491	0.755	0.500	0.388	0.299	0.252
18	0.341	0.296	0.295	0.297	0.294	0.492	0.491	0.768	0.667	0.382	0.301	0.248
19	0.335	0.296	0.295	0.296	0.294	0.492	0.491	0.777	0.520	0.379	0.297	0.246
20	0.330	0.294	0.296	0.296	0.294	0.492	0.490	0.775	0.494	0.380	0.291	0.247
21	0.332	0.294	0.296	0.297	0.294	0.491	0.476	0.768	0.486	0.388	0.287	0.244
22	0.328	0.294	0.294	0.297	0.294	0.491	0.523	0.750	0.476	0.472	0.285	0.244
23	0.327	0.295	0.295	0.295	0.294	0.491	0.691	0.735	0.453	0.410	0.295	0.244
24	0.319	0.297	0.295	0.294	0.294	0.491	0.738	0.728	0.448	0.389	0.309	0.245
25	0.315	0.295	0.295	0.295	0.294	0.491	0.718	0.696	0.446	0.383	0.291	0.250
26	0.315	0.295	0.295	0.295	0.294	0.492	0.788	0.670	0.443	0.377	0.289	0.259
27	0.311	0.295	0.294	0.296	0.294	0.491	0.959	0.641	0.444	0.375	0.293	0.251
28	0.305	0.294	0.294	0.295	0.294	0.491	1.134	0.643	0.438	0.378	0.294	0.247
29	0.302	0.295	0.294	0.296		0.491	1.214	0.639	0.435	0.374	0.293	0.243
30	0.296	0.294	0.296	0.296		0.491	1.252	0.612	0.444	0.367	0.301	0.243
31	0.294		0.295	0.295		0.491		0.597		0.360	0.319	
MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	10.457	8.848	9.144	9.170	8.241	14.436	18.313	26.914	15.186	12.577	9.687	7.760
TOTAL FLOW (cms days)	0.296	0.251	0.259	0.260	0.233	0.409	0.519	0.762	0.430	0.356	0.274	0.220
TOTAL DEPTH (in)	0.461	0.390	0.403	0.404	0.363	0.636	0.807	1.186	0.669	0.554	0.427	0.342
TOTAL DEPTH (cm)	1.171	0.991	1.024	1.027	0.923	1.616	2.050	3.013	1.700	1.408	1.085	0.869

ANNUAL SUMMARY:
Sum of Mean Daily Flow 150.734 cfs = 4.269 cms
Total Depth 6.644 in = 16.876 cm
Maximum Instantaneous Flow 1.301 cfs = 0.037 cms on May 2 at 5.00 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 13
WATERSHED AREA: 540 ACRES (218 HECTARES)

WATER YEAR 1980
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.244	0.262	0.271	0.242	0.246	0.500	0.312	1.824	1.131	0.760	0.509	0.367
2	0.245	0.259	0.275	0.238	0.241	0.493	0.312	1.692	1.294	0.847	0.498	0.399
3	0.242	0.259	0.278	0.237	0.243	0.460	0.314	1.597	1.357	0.940	0.496	0.385
4	0.240	0.262	0.285	0.237	0.242	0.433	0.319	1.532	1.336	0.797	0.494	0.362
5	0.238	0.264	0.273	0.238	0.239	0.422	0.356	1.477	1.292	0.757	0.486	0.360
6	0.237	0.257	0.271	0.239	0.239	0.403	0.366	1.432	1.247	0.732	0.479	0.354
7	0.236	0.252	0.269	0.240	0.238	0.372	0.363	1.363	1.192	0.725	0.480	0.350
8	0.236	0.251	0.271	0.241	0.240	0.347	0.372	1.325	1.138	0.711	0.475	0.340
9	0.239	0.250	0.271	0.242	0.240	0.334	0.470	1.291	1.094	0.694	0.471	0.332
10	0.240	0.250	0.267	0.244	0.239	0.333	0.558	1.248	1.061	0.674	0.465	0.388
11	0.238	0.247	0.266	0.247	0.239	0.336	0.582	1.182	1.032	0.659	0.456	0.361
12	0.239	0.242	0.260	0.311	0.239	0.323	0.607	1.134	1.038	0.656	0.450	0.337
13	0.237	0.240	0.257	0.458	0.243	0.328	0.730	1.111	1.023	0.650	0.444	0.423
14	0.237	0.238	0.262	0.698	0.243	0.405	0.881	1.085	1.081	0.662	0.439	0.370
15	0.301	0.236	0.267	0.604	0.242	0.432	1.009	1.095	1.031	0.646	0.443	0.350
16	0.273	0.240	0.265	0.425	0.241	0.395	1.053	1.067	0.994	0.629	0.440	0.336
17	0.271	0.251	0.265	0.354	0.249	0.375	1.231	1.016	0.964	0.626	0.428	0.326
18	0.280	0.249	0.265	0.315	0.334	0.367	1.621	0.976	0.949	0.625	0.465	0.396
19	0.340	0.238	0.264	0.295	0.529	0.350	1.841	0.934	0.930	0.616	0.432	0.358
20	0.288	0.230	0.262	0.290	0.622	0.357	2.175	0.898	0.921	0.608	0.419	0.346
21	0.288	0.232	0.262	0.284	0.583	0.386	2.426	0.872	0.905	0.596	0.409	0.340
22	0.289	0.238	0.260	0.276	0.453	0.403	2.376	0.883	0.901	0.583	0.408	0.327
23	0.328	0.242	0.255	0.270	0.389	0.408	2.500	0.945	0.922	0.575	0.400	0.321
24	0.295	0.244	0.257	0.265	0.356	0.394	2.629	0.879	0.880	0.564	0.389	0.315
25	0.306	0.247	0.261	0.262	0.345	0.375	2.580	0.927	0.845	0.552	0.390	0.315
26	0.349	0.250	0.257	0.257	0.364	0.355	2.247	0.986	0.829	0.543	0.385	0.320
27	0.296	0.253	0.250	0.253	0.464	0.345	2.145	0.972	0.812	0.535	0.390	0.325
28	0.286	0.258	0.248	0.252	0.623	0.327	2.160	0.966	0.795	0.532	0.375	0.319
29	0.278	0.264	0.249	0.251	0.535	0.323	2.171	1.001	0.778	0.523	0.373	0.314
30	0.269	0.267	0.248	0.246		0.316	2.018	1.033	0.768	0.510	0.370	0.304
31	0.262		0.245	0.244		0.313		1.077		0.509	0.372	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	8.344	7.473	8.156	9.253	9.699	11.710	38.723	35.819	30.539	20.034	13.534	10.439
TOTAL FLOW (cms days)	0.236	0.212	0.231	0.262	0.275	0.332	1.097	1.014	0.865	0.567	0.383	0.296
TOTAL DEPTH (in)	0.368	0.329	0.359	0.408	0.427	0.516	1.707	1.579	1.346	0.883	0.597	0.460
TOTAL DEPTH (cm)	0.934	0.837	0.913	1.036	1.086	1.311	4.335	4.010	3.419	2.243	1.515	1.169

ANNUAL SUMMARY:
Sum of Mean Daily Flow 203.721 cfs = 5.769 cms
Total Depth 8.979 in = 22.808 cm
Maximum Instantaneous Flow 2.810 cfs = 0.080 cms on April 24 at 21.02 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 13
WATERSHED AREA: 540 ACRES (218 HECTARES)

WATER YEAR 1981
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.330	0.296	0.276	0.438*	0.290	0.456*	0.478*	0.698*	0.878	0.937	0.594	0.410
2	0.326	0.291	0.350	0.415*	0.291*	0.451*	0.468*	0.713*	0.874	0.917	0.585	0.407
3	0.318	0.290	0.573	0.396*	0.302*	0.448*	0.470*	0.723*	0.860	0.893	0.575	0.401
4	0.311	0.290	0.788	0.381*	0.309*	0.445*	0.459*	0.743*	0.837	0.872	0.569	0.402
5	0.311	0.289	0.518	0.369*	0.302	0.448*	0.464*	0.746*	0.820	0.863	0.558	0.400
6	0.307	0.312	0.386	0.360*	0.295*	0.439*	0.449*	0.748*	0.870	0.930	0.545	0.397
7	0.303	0.479	0.334*	0.351*	0.295*	0.435*	0.437*	0.747*	0.887	0.900	0.535	0.393
8	0.304	0.345	0.312*	0.343*	0.295*	0.431*	0.431*	0.752*	1.043	0.847	0.529	0.389
9	0.302	0.319	0.306*	0.339*	0.293*	0.428*	0.438*	0.746*	1.249	0.829	0.526	0.384
10	0.302	0.317	0.305*	0.329*	0.284*	0.427*	0.424*	0.772*	1.218	0.836	0.521	0.380
11	0.300	0.311	0.304*	0.322*	0.289*	0.432*	0.417*	0.764*	1.148	0.823	0.510	0.375
12	0.328	0.308	0.296*	0.321*	0.292*	0.432*	0.412*	0.737*	1.210	0.813	0.498	0.368
13	0.324	0.293	0.282*	0.317*	0.293*	0.429*	0.403*	0.703	1.253	0.801	0.486	0.363
14	0.313	0.279	0.284*	0.315*	0.295*	0.426*	0.407*	0.758	1.288	0.792	0.477	0.362
15	0.325	0.278	0.306*	0.311*	0.296*	0.424*	0.431*	0.837	1.280	0.781	0.471	0.361
16	0.321	0.299	0.304*	0.314*	0.449*	0.438*	0.440*	0.851	1.253	0.772	0.467	0.358
17	0.313	0.285	0.299*	0.300	0.455*	0.422*	0.437*	0.821	1.208	0.758	0.463	0.354
18	0.311	0.283	0.293*	0.298	0.458*	0.415*	0.448*	0.791	1.165	0.746	0.464	0.350
19	0.310	0.283	0.286*	0.298	0.653*	0.418*	0.476*	0.787	1.349	0.730	0.470	0.349
20	0.308	0.279	0.286*	0.295	0.678*	0.421*	0.508*	0.858	1.412	0.711	0.465	0.351
21	0.302	0.283	0.333*	0.291	0.614*	0.413*	0.525*	1.018	1.389	0.698	0.455	0.350
22	0.302	0.292	0.462*	0.293	0.565*	0.437*	0.511*	1.112	1.320	0.683	0.449	0.352
23	0.303	0.280	0.413*	0.330	0.537*	0.423*	0.528*	1.111	1.264	0.667	0.446	0.354
24	0.306	0.277	0.397*	0.334	0.523*	0.415*	0.551*	1.057	1.212	0.660	0.439	0.352
25	0.335	0.278	0.509*	0.309	0.505*	0.436*	0.588*	1.056	1.156	0.662	0.434	0.372
26	0.337	0.272	0.799*	0.304	0.490*	0.474*	0.660*	1.014	1.111	0.653	0.427	0.373
27	0.316	0.272	0.772*	0.304	0.471*	0.450*	0.705*	0.967*	1.065	0.638	0.421	0.390
28	0.310	0.276	0.639*	0.317	0.461*	0.441*	0.673*	0.891	1.016	0.629	0.419	0.517
29	0.308	0.280	0.548*	0.308		0.464*	0.678*	0.852	0.985	0.618	0.414	0.377
30	0.307	0.282	0.497*	0.302		0.450*	0.684*	0.890	0.959	0.612	0.419	0.368
31	0.303		0.464*	0.296		0.448*		0.917		0.601	0.415	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	9.696	8.919	12.921	10.200	11.282	13.515	14.999	26.179	33.577	23.669	15.046	11.360
TOTAL FLOW (cms days)	0.275	0.253	0.366	0.289	0.320	0.383	0.425	0.741	0.951	0.670	0.426	0.322
TOTAL DEPTH (in)	0.427	0.393	0.570	0.450	0.497	0.596	0.661	1.154	1.480	1.043	0.663	0.501
TOTAL DEPTH (cm)	1.086	0.998	1.447	1.142	1.263	1.513	1.679	2.931	3.759	2.650	1.685	1.272

ANNUAL SUMMARY:
Sum of Mean Daily Flow 191.363 cfs = 5.419 cms
Total Depth 8.435 in = 21.424 cm
Maximum Instantaneous Flow 1.585 cfs = 0.045 cms on June 19 at 6.99 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 13
WATERSHED AREA: 540 ACRES (218 HECTARES)

WATER YEAR 1982
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.359	0.317	0.315	0.364	0.306	0.869	0.754	2.723	3.418	2.103	0.891	0.555
2	0.356	0.314	0.337	0.354	0.303	0.929	0.713	3.518	3.219	2.014	0.876	0.549
3	0.380	0.313	0.317	0.347	0.307	0.948	0.711	4.186	3.060	1.945	0.855	0.540
4	0.368	0.313	0.315	0.355	0.302*	0.939	0.692	3.589	3.005	1.920	0.835	0.532
5	0.358	0.313	0.333	0.349	0.302*	0.884	0.660	3.034	3.038	1.829	0.816	0.526
6	0.349	0.310	0.668	0.348	0.303*	0.838	0.655	2.777	2.995	1.752	0.796	0.519
7	0.369	0.308	0.823	0.347	0.303*	0.816	0.636	2.747	3.009	1.774	0.785	0.513
8	0.372	0.306	0.638	0.346	0.303*	0.787	0.618	2.894	3.025	1.692	0.795	0.504
9	0.364	0.304	0.606	0.346	0.302*	0.779	0.614	2.694	2.870	1.603	0.781	0.498
10	0.387	0.305	0.934	0.345	0.301*	0.796	0.646	2.559	2.699	1.521	0.749	0.527
11	0.426	0.305	0.721	0.338	0.299*	0.912	1.469	2.452	2.560	1.473	0.747	0.520
12	0.388	0.342	0.557	0.319	0.298*	0.951	2.360	2.404	2.497	1.418	0.737	0.560
13	0.365	0.342	0.488	0.311	0.296*	0.919	2.153	2.421	2.546	1.370	0.711	0.546
14	0.356	0.387	0.451	0.309	0.294*	0.900	2.049	2.794	2.663	1.330	0.692	0.523
15	0.349	0.362	0.462	0.302	0.291*	0.898	1.826	3.209	2.795	1.285	0.676	0.512
16	0.345	0.479	0.448	0.304	0.290*	0.878	1.611	3.691	2.913	1.254	0.660	0.500
17	0.339	0.509	0.433	0.323	0.288*	0.867	1.471	3.881	2.989	1.228	0.649	0.488
18	0.336	0.431	0.430	0.319	0.283*	0.852	1.337	3.763	3.058	1.202	0.642	0.476
19	0.332	0.370	0.762	0.316	0.316	0.816	1.212	3.381	3.100	1.161	0.633	0.501
20	0.330	0.346	1.759	0.309	1.089	0.766	1.113	3.029	3.099	1.132	0.626	0.550
21	0.328	0.378	1.172	0.307	3.626	0.726	1.072	2.913	3.056	1.114	0.604	0.496
22	0.327	0.492	0.872	0.305	4.146	0.704	1.181	3.046	3.000	1.095	0.595	0.469
23	0.329	0.437	0.680	0.302	1.669	0.684	1.535	3.204	2.923	1.077	0.597	0.457
24	0.329	0.397	0.584	0.290	0.771	0.683	2.020	3.447	2.796	1.061	0.613	0.458
25	0.326	0.363	0.529	0.286	0.440	0.702	2.318	3.833	2.715	1.037	0.605	0.486
26	0.354	0.345	0.484	0.311	0.346	0.788	2.356	5.002	2.561	1.010	0.599	0.596
27	0.329	0.335	0.452	0.310	0.632	0.811	2.444	5.773	2.484	0.987	0.589	0.554
28	0.330	0.326	0.429	0.306	0.782	0.840	2.744	5.387	2.461	0.974	0.580	0.513
29	0.327	0.324	0.403	0.306		0.839	2.645	4.824	2.351*	0.953	0.585	0.551
30	0.324	0.317	0.389	0.308		0.801	2.594	4.254	2.152*	0.926	0.585	0.493
31	0.324		0.375	0.309		0.781		3.794		0.906	0.571	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	10.856	10.693	18.164	9.992	19.190	25.702	44.210	107.224	85.060	42.147	21.473	15.517
TOTAL FLOW (cms days)	0.307	0.303	0.514	0.283	0.543	0.728	1.252	3.037	2.409	1.194	0.608	0.439
TOTAL DEPTH (in)	0.478	0.471	0.801	0.440	0.846	1.133	1.949	4.726	3.749	1.858	0.946	0.684
TOTAL DEPTH (cm)	1.215	1.197	2.034	1.119	2.148	2.877	4.950	12.004	9.523	4.719	2.404	1.737

ANNUAL SUMMARY:
Sum of Mean Daily Flow 410.227 cfs = 11.618 cms
Total Depth 18.082 in = 45.927 cm
Maximum Instantaneous Flow 5.876 cfs = 0.166 cms on May 27 at 16.98 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 14
WATERSHED AREA: 389 ACRES (157 HECTARES)

WATER YEAR 1968
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.825	0.653	0.541	0.573	0.503	0.850	0.859	0.819	1.205	1.051	0.881	0.756
2	0.936	0.643	0.539	0.561	0.542	0.858	0.887	0.840	1.202	1.041	0.869	0.755
3	0.967	0.640	0.544	0.558	0.561	0.862	0.843	0.873	1.249	1.030	0.870	0.754
4	0.761	0.638	0.553	0.567	0.559	0.898	0.850	0.925	1.210	1.027	0.871	0.750
5	0.757	0.635	0.549	0.558	0.585	0.969	0.882	0.965	1.207	1.013	0.873	0.742
6	0.739	0.635	0.519	0.528	0.605	1.011	0.839	0.977	1.233	1.001	0.869	0.737
7	0.727	0.635	0.515	0.515	0.608	0.977	0.825	0.984	1.235	0.997	0.865	0.730
8	0.715	0.636	0.512	0.508	0.600	0.930	0.804	0.988	1.223	0.988	0.859	0.715
9	0.711	0.651	0.510	0.534	0.584	0.881	0.773	0.997	1.215	1.027	0.860	0.697
10	0.707	0.695	0.513	0.584	0.576	0.836	0.833	1.011	1.209	1.034	0.834	0.682
11	0.719	0.709	0.500	0.545	0.570	0.802	0.870	1.033	1.228	1.003	0.815	0.673
12	0.767	0.655	0.486	0.545	0.555	0.785	0.848	1.087	1.198	1.011	0.803	0.687
13	0.727	0.640	0.596	0.551	0.538	0.771	0.825	1.129	1.205	0.998	0.832	0.684
14	0.723	0.643	0.645	0.561	0.530	0.754	0.813	1.175	1.205	0.985	0.873	0.708
15	0.706	0.657	0.733	0.589	0.528	0.742	0.801	1.160	1.191	0.969	0.887	0.763
16	0.695	0.629	0.808	0.591	0.528	0.739	0.786	1.143	1.179	0.961	0.833	0.740
17	0.690	0.622	0.733*	0.553	0.535	0.733	0.769	1.140	1.171	0.954	0.835	0.715
18	0.678	0.618	0.559	0.545	0.559	0.716	0.755	1.142	1.134	0.940	0.874	0.701
19	0.669	0.611	0.466	0.545	0.758	0.703	0.742	1.142	1.138	0.934	0.855	0.694
20	0.664	0.608	0.470	0.545	0.967	0.689	0.730	1.212	1.141	0.932	0.863	0.701
21	0.715	0.605	0.470	0.548	1.041	0.679	0.720	1.204	1.107	0.926	0.842	0.716
22	0.716	0.605	0.487	0.548	1.034	0.692	0.711	1.221	1.141	0.924	0.821	0.716
23	0.703	0.605	0.509	0.545	1.071	0.714	0.713	1.199	1.111	0.925	0.817	0.711
24	0.676	0.600	0.546	0.555	1.110	0.731	0.715	1.205	1.076	0.928	0.789	0.698
25	0.665	0.590	0.629	0.555	1.031	0.775	0.710	1.228	1.057	0.927	0.783	0.689
26	0.656	0.602	0.696	0.546	0.955	0.759	0.704	1.225	1.065	0.924	0.798	0.684
27	0.677	0.594	0.643	0.555	0.889	0.762	0.708	1.217	1.060	0.916	0.791	0.675
28	0.819	0.556	0.618	0.567	0.855	0.789	0.724	1.204	1.051	0.914	0.772	0.666
29	0.695	0.564	0.603	0.570	0.845	0.870	0.762	1.205	1.071	0.896	0.751	0.663
30	0.673	0.558	0.590	0.484		0.861	0.792	1.203	1.062	0.897	0.762	0.660
31	0.665		0.579	0.479		0.841		1.204		0.893	0.760	

MONTHLY SUMMARY:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	22.542	18.732	17.662	17.009	20.621	24.982	23.593	34.057	34.776	29.969	25.807	21.263
TOTAL FLOW (cms days)	0.638	0.530	0.500	0.482	0.584	0.707	0.668	0.964	0.985	0.849	0.731	0.602
TOTAL DEPTH (in)	1.379	1.146	1.081	1.041	1.262	1.529	1.444	2.084	2.128	1.834	1.579	1.301
TOTAL DEPTH (cm)	3.503	2.911	2.745	2.643	3.205	3.883	3.667	5.293	5.405	4.658	4.011	3.305

ANNUAL SUMMARY:

Sum of Mean Daily Flow 291.012 cfs = 8.241 cms
Total Depth 17.806 in = 45.227 cm
Maximum Instantaneous Flow 1.619 cfs = 0.046 cms on October 3 at 1.00 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 14
WATERSHED AREA: 389 ACRES (157 HECTARES)

WATER YEAR 1969
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.652	0.592	0.572	0.568	0.576	0.546	1.318	1.413	1.777	1.270	0.899	0.676
2	0.640	0.592	0.567	0.545	0.576	0.560	1.433	1.397	1.757	1.259	0.890	0.670
3	0.637	0.600	0.571	0.540	0.571	0.584	1.496	1.383	1.735	1.251	0.883	0.669
4	0.637	0.602	0.574	0.553	0.561	0.600	1.427	1.371	1.702	1.240	0.878	0.670
5	0.637	0.592	0.575	0.600	0.561	0.620	1.580	1.370	1.708	1.224	0.888	0.670
6	0.634	0.587	0.561	0.632	0.555	0.616	1.780	1.381	1.652	1.226	0.886	0.663
7	0.630	0.584	0.563	0.647	0.547	0.598	1.596	1.429	1.609	1.210	0.880	0.654
8	0.626	0.598	0.568	0.622	0.545	0.584	1.415	1.568	1.613	1.186	0.873	0.646
9	0.614	0.668	0.563	0.599	0.547	0.575	1.355	1.693	1.614	1.168	0.860	0.640
10	0.606	0.610	0.588	0.586	0.547	0.579	1.373	1.778	1.587	1.158	0.854	0.645
11	0.633	0.636	0.597	0.578	0.548	0.569	1.355	1.846	1.519	1.138	0.863	0.670
12	0.735	0.851	0.570	0.574	0.559	0.565	1.372	1.903	1.500	1.132	0.847	0.697
13	0.648	0.655	0.603	0.782	0.547	0.568	1.436	1.966	1.477	1.122	0.822	0.679
14	0.614	0.615	0.568	0.935	0.540	0.577	1.403	2.030	1.453	1.114	0.817	0.656
15	0.625	0.606	0.572	0.833	0.542	0.592	1.344	2.104	1.433	1.099	0.805	0.649
16	0.619	0.593	0.571	0.728	0.542	0.606	1.303	2.033	1.417	1.084	0.790	0.643
17	0.627	0.586	0.554	0.680	0.538	0.630	1.308	2.009	1.403	1.072	0.799	0.638
18	0.639	0.600	0.554	0.643	0.538	0.658	1.385	2.019	1.389	1.062	0.792	0.637
19	0.630	0.612	0.552	0.632	0.546	0.649	1.350	2.068	1.395	1.050	0.777	0.678
20	0.643	0.617	0.564	0.618	0.548	0.649	1.324	2.062	1.407	1.040	0.746	0.731
21	0.629	0.614	0.570	0.828	0.557	0.663	1.346	1.996	1.371	1.028	0.739	0.680
22	0.618	0.700	0.570	0.861	0.565	0.687	1.484	1.980	1.375	1.020	0.727	0.652
23	0.611	0.642	0.570	0.772	0.570	0.687	1.702	1.971	1.419	1.010	0.723	0.641
24	0.608	0.623	0.583	0.720	0.562	0.677	1.782	1.960	1.394	1.008	0.712	0.653
25	0.606	0.608	0.569	0.701	0.558	0.684	1.724	1.938	1.372	1.007	0.710	0.641
26	0.602	0.594	0.551	0.658	0.549	0.724	1.652	1.897	1.385	0.982	0.709	0.631
27	0.598	0.590	0.553	0.605	0.543	0.783	1.541	1.873	1.421	0.953	0.704	0.624
28	0.597	0.579	0.553	0.588	0.543	0.837	1.489	1.857*	1.365	0.934	0.705	0.617
29	0.592	0.580	0.541	0.577		0.929	1.461	1.876	1.325	0.929	0.693	0.614
30	0.612	0.583	0.553	0.576		1.058	1.426	1.879	1.297	0.917	0.687	0.658
31	0.598		0.565	0.576		1.209		1.813		0.910	0.682	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	19.396	18.510	17.584	20.360	15.482	20.863	43.960	55.863	44.873	33.803	24.638	19.693
TOTAL FLOW (cms days)	0.549	0.524	0.498	0.577	0.438	0.591	1.245	1.582	1.271	0.957	0.698	0.558
TOTAL DEPTH (in)	1.187	1.133	1.076	1.246	0.947	1.277	2.690	3.418	2.746	2.068	1.508	1.205
TOTAL DEPTH (cm)	3.014	2.877	2.733	3.164	2.406	3.242	6.832	8.682	6.974	5.254	3.829	3.061

ANNUAL SUMMARY:
Sum of Mean Daily Flow 335.023 cfs = 9.488 cms
Total Depth 20.499 in = 52.067 cm
Maximum Instantaneous Flow 2.436 cfs = 0.069 cms on May 19 at 23.25 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 14
WATERSHED AREA: 389 ACRES (157 HECTARES)

WATER YEAR 1970
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.678	0.606	0.574	0.533*	0.499	0.700	0.638	0.665	2.123	1.713	1.180	0.907
2	0.706	0.603	0.572	0.521*	0.475	0.662	0.640	0.722	2.059	1.660	1.168	0.873
3	0.670	0.598	0.570	0.509*	0.470	0.648	0.631	0.829	2.017	1.621	1.154	0.890
4	0.657	0.589	0.570	0.497*	0.454	0.645	0.629	0.979	2.003	1.597	1.141	1.020
5	0.652	0.629	0.570	0.485*	0.454	0.648	0.662	1.158	1.998	1.581	1.149	0.939
6	0.650	0.632	0.575	0.473*	0.471	0.658	0.756	1.283	1.993	1.570	1.128	0.920
7	0.649	0.614	0.579	0.462*	0.498	0.720	0.812	1.293	2.012	1.540	1.112	1.119
8	0.678	0.600	0.576	0.450*	0.529	0.711	0.797	1.239	1.999	1.523	1.106	1.011
9	0.680	0.594	0.578	0.439*	0.569	0.717	0.826	1.214	2.001	1.504	1.096	0.894
10	0.676	0.590	0.579	0.427*	0.599	0.727	0.955	1.181	1.971	1.506	1.086	0.878
11	0.662	0.587	0.584	0.416*	0.616	0.725	0.942	1.128	1.934	1.480	1.074	0.849
12	0.648	0.584	0.658	0.405*	0.673	0.718	0.896	1.096	1.933	1.519	1.063	0.844
13	0.645	0.583	0.639	0.394*	0.705	0.716	0.859	1.052	1.896	1.452	1.049	0.847
14	0.645	0.583	0.621	0.386*	0.695	0.754	0.824	1.027	1.948	1.430	1.042	0.840
15	0.643	0.585	0.609	0.377*	0.680	0.767	0.788	1.036	1.895	1.412	1.032	0.819
16	0.649	0.587	0.595	0.367*	0.686	0.776	0.763	1.101	1.836	1.395	1.020	0.804
17	0.645	0.577	0.598	0.356*	0.739	0.770	0.751	1.249	1.771*	1.377	1.006	0.797
18	0.645	0.573	0.607	0.345*	0.714	0.753	0.744	1.679	1.733*	1.364	0.999	0.803
19	0.640	0.578	0.626	0.335*	0.697	0.731	0.741	1.909	1.779	1.347	0.992	0.880
20	0.637	0.578	0.663	0.325*	0.684	0.718	0.729	1.930	1.748	1.332	0.981	0.829
21	0.634	0.578	0.862	0.314*	0.671	0.706	0.722	1.908	1.721	1.327	0.975	0.810
22	0.628	0.571	0.726	0.382	0.655	0.691	0.706	1.915	1.692	1.319	0.967	0.791
23	0.620	0.572	0.651	0.532	0.643	0.682	0.695	2.332	1.690	1.300	0.963	0.802
24	0.626	0.573	0.626	0.935	0.635	0.684	0.686	2.247	1.686	1.280	0.956	0.780
25	0.618	0.572	0.613	0.688	0.625	0.666	0.672	2.287	1.619	1.268	0.942	0.773
26	0.614	0.576	0.611	0.565	0.623	0.671	0.672	2.355	1.599	1.260	0.932	0.769
27	0.624	0.581	0.603	0.635	0.625	0.664	0.663	2.430	1.818	1.246	0.924	0.760
28	0.638	0.578	0.602	0.643	0.633	0.672	0.662	2.451	1.724	1.247	0.917	0.753
29	0.616	0.576	0.584*	0.583		0.673	0.651	2.418	1.913	1.235	0.915	0.749
30	0.613	0.580	0.558*	0.543		0.663	0.650	2.343	1.805	1.212	0.912	0.740
31	0.609		0.545*	0.519		0.649		2.206		1.197	0.912	

MONTHLY SUMMARY:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	19.993	17.627	18.926	14.838	17.017	21.683	22.164	48.663	55.917	43.812	31.891	25.489
TOTAL FLOW (cms days)	0.566	0.499	0.536	0.420	0.482	0.614	0.628	1.378	1.584	1.241	0.903	0.722
TOTAL DEPTH (in)	1.223	1.079	1.158	0.908	1.041	1.327	1.356	2.978	3.421	2.681	1.951	1.560
TOTAL DEPTH (cm)	3.107	2.740	2.941	2.306	2.645	3.370	3.445	7.563	8.690	6.809	4.956	3.961

ANNUAL SUMMARY:
Sum of Mean Daily Flow 338.021 cfs = 9.573 cms
Total Depth 20.682 in = 52.533 cm
Maximum Instantaneous Flow 3.236 cfs = 0.092 cms on May 23 at 3.50 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 14
WATERSHED AREA: 389 ACRES (157 HECTARES)

WATER YEAR 1971
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.734	0.617	0.626	0.478	1.273	0.724	1.189	1.993	4.114	-----	1.348	0.991
2	0.727	0.612	0.637	0.470	1.261	0.710	1.166	2.344	3.887	-----	1.361	1.061
3	0.724	0.605	0.626	0.473	1.163	0.696	1.162	2.861	3.725	-----	1.333	0.980
4	0.718	0.610	0.613	0.481	1.076	0.685	1.180	3.261	-----	-----	1.307	0.967
5	0.718	0.642	0.617	0.480	1.001	0.671	1.244	3.479	-----	-----	1.294	0.951
6	0.721	0.664	0.665	0.467	0.852*	0.660	1.385	3.459	-----	-----	1.298	0.964
7	0.712	0.666	0.732	0.466	0.777*	0.656	1.660	3.479	-----	1.796*	1.273	0.970*
8	0.700	0.639	0.817	0.467	0.736*	0.652	1.724	3.561	-----	1.780	1.248	0.977*
9	0.725	0.670	0.753	0.462	0.713*	0.645	1.680	3.584	-----	1.761	1.234	0.964*
10	0.723	0.647	0.695	0.457*	0.691*	0.647	1.699	3.636	-----	1.785	1.213	0.955*
11	0.693	0.640	0.661	0.456*	0.673*	0.650	1.608	3.815	-----	1.728	1.209	0.947*
12	0.683	0.637	0.629	0.456*	0.668	0.696	1.483	4.038	-----	1.714	1.201	0.943*
13	0.673	0.616	0.697*	0.456*	0.721	0.704	1.397	4.276	-----	1.690	1.184	0.938*
14	0.671	0.607	0.541*	0.470*	0.788	0.701	1.453	4.262	-----	1.670	1.178	0.937*
15	0.668	0.605	0.489	0.494*	0.870	0.697	1.675	4.202	-----	1.642	1.161	0.901*
16	0.665	0.607	0.496	0.541*	0.922	0.676	1.701	4.166	-----	1.599	1.146	0.899*
17	0.661	0.597	0.507	0.699*	0.931	0.658	1.671	4.000	-----	1.592	1.142	0.897*
18	0.659	0.594	0.498	0.684*	0.917	0.640	1.575	3.830	-----	1.587	1.133	0.895*
19	0.653	0.583	0.495	0.786*	0.891	0.643	1.508	3.654	-----	1.605	1.116	0.888*
20	0.672	0.584	0.494	1.245*	0.853	0.653	1.538	3.459	-----	1.573	1.103	0.884*
21	0.658	0.572	0.495	1.113	0.820	0.664	1.651	3.249*	-----	1.643	1.094	0.880*
22	0.674	0.611	0.503	0.963	0.815	0.683	1.715	3.077	-----	1.632	1.083	0.834*
23	0.692	0.607	0.503	0.874	0.803	0.736	1.738	3.006	-----	1.515	1.077	0.824*
24	0.695*	0.895	0.503	0.815	0.797	0.839	1.719	2.965	-----	1.492	1.066	0.815*
25	0.660	0.784	0.503	0.776	0.769	0.924	1.666	2.986	-----	1.475	1.062	0.831*
26	0.645	0.710	0.503	0.762	0.746	1.128	1.593	3.080	-----	1.451	1.053	0.857*
27	0.633	0.668	0.500	0.793	0.751	1.304	1.555	3.228	-----	1.439	1.036	0.849*
28	0.638	0.653	0.501	0.740	0.735	1.188	1.599	3.499	-----	1.415	1.021	0.841*
29	0.637	0.633	0.517	0.738		1.124	1.696	3.819	-----	1.398	1.014	0.846*
30	0.626	0.653	0.509	0.782		1.164	1.809	4.126	-----	1.383	1.007	0.839
31	0.621		0.504	0.981		1.217		4.157		1.364	0.996	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	21.078	19.229	17.828	20.326	24.014	24.436	46.440	108.552	11.726	39.730	35.988	27.328
TOTAL FLOW (cms days)	0.597	0.545	0.505	0.576	0.680	0.692	1.315	3.074	0.332	1.125	1.019	0.774
TOTAL DEPTH (in)	1.290	1.177	1.091	1.244	1.469	1.495	2.841	6.642	0.717	2.431	2.202	1.672
TOTAL DEPTH (cm)	3.276	2.989	2.771	3.159	3.732	3.798	7.217	16.871	1.822	6.175	5.593	4.247

ANNUAL SUMMARY:
Sum of Mean Daily Flow 396.674 cfs = 11.234 cms
Total Depth 24.271 in = 61.649 cm
Maximum Instantaneous Flow 4.365 cfs = 0.124 cms on June 1 at 10.25 hours

* Indicates some data were estimated during this day.
Summaries exclude missing data.

TAILHOLT CREEK STUDY AREA
WATERSHED: 14
WATERSHED AREA: 389 ACRES (157 HECTARES)

WATER YEAR 1972
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.818	0.706	0.664	0.552	0.542	1.143	0.836	1.302	3.005	1.520	1.118	0.791
2	0.801	0.697	0.664	0.549	0.553	0.916	0.871	1.269	3.115	1.492	1.093	0.785
3	0.796	0.700	0.671	0.531	0.566	0.797	0.872	1.323	3.162	1.466	1.077	0.779
4	0.787	0.700	0.662	0.531	0.575	0.735	0.893	1.448	3.096	1.443	1.062	0.771
5	0.778	0.679	0.680	0.531	0.580	0.707	0.999	1.585	3.010	1.427	1.043	0.809
6	0.770	0.683	0.677	0.552	0.582	0.752	1.130	1.790	2.916	1.424	1.027	0.807
7	0.766	0.687	0.650*	0.578	0.582	0.806	1.145	1.901	2.841	1.407	1.011	0.779
8	0.758	0.687	0.643*	0.562	0.596	0.811	1.113	2.008	2.775	1.382	1.003	0.765
9	0.749	0.686	0.635*	0.565	0.600	0.873	1.073	1.925	2.677	1.415	1.000	0.757
10	0.743	0.694	0.630*	0.559	0.596	1.125	1.028	1.857	2.651	1.379	0.986	0.761
11	0.744	0.692	0.626*	0.566	0.596	1.396	1.033	1.806	2.512	1.345	0.969	0.795
12	0.738	0.723	0.619*	0.554	0.598	1.447	1.040	1.794	2.402	1.304	0.958	0.810
13	0.736	0.692	0.614*	0.544	0.609	1.614	1.017	1.867	2.322	1.286	0.950	0.777
14	0.744	0.676	0.608*	0.543	0.591	1.695	1.000	2.108	2.250	1.277	0.941	0.762
15	0.753	0.671	0.601*	0.541	0.593	1.537	0.987	2.477	2.177	1.290	0.954	0.749
16	0.751	0.664	0.595*	0.541	0.597	1.553	1.012	2.737	2.132	1.278	0.923	0.738
17	0.756	0.661	0.592*	0.566	0.589	1.687	0.989	2.939	2.068	1.263	0.908	0.729
18	0.751	0.652	0.590*	0.567	0.610	1.826	0.982	2.984	2.028	1.250	0.917	0.719
19	0.778	0.656	0.586*	0.576	0.608	1.697	0.969	2.946	1.974	1.278	0.907	0.723
20	0.803	0.658	0.581*	0.638	0.668	1.509	0.957	2.891	1.920	1.254	0.895	0.709
21	0.759	0.653	0.575*	0.726	0.661	1.392	0.968	2.837	1.879	1.264	0.881	0.704
22	0.745	0.646	0.570*	0.627	0.704	1.407	0.928	2.807*	1.835	1.234	0.879	0.710
23	0.740	0.639	0.565*	0.591	0.676	1.479	0.933	2.815	1.810	1.212	0.875	0.711
24	0.733	0.654	0.564*	0.566	0.627	1.367	1.015	2.743	1.779	1.196	0.859	0.722
25	0.722	0.644	0.564*	0.563	0.590	1.247	1.068	2.620	1.789	1.183	0.845	0.721
26	0.719	0.659	0.560	0.553	0.574	1.128	1.071	2.479	1.738	1.165	0.835	0.706
27	0.715	0.690	0.553	0.542	0.746	1.043	1.138	2.474	1.668	1.156	0.829	0.716
28	0.699	0.683	0.592	0.540	1.216	0.974	1.330	2.510	1.614	1.131	0.846	0.710
29	0.696	0.681	0.604	0.539	1.885	0.916	1.423	2.603	1.576	1.119	0.837	0.703
30	0.708	0.676	0.553	0.538		0.881	1.353	2.712	1.552	1.111	0.812	0.697
31	0.706		0.554	0.537		0.858		2.853		1.144	0.801	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	23.261	20.287	18.838	17.466	19.512	37.320	31.173	70.410	68.273	40.093	29.043	22.414
TOTAL FLOW (cms days)	0.659	0.575	0.533	0.495	0.553	1.057	0.883	1.994	1.933	1.135	0.822	0.635
TOTAL DEPTH (in)	1.423	1.241	1.153	1.069	1.194	2.284	1.907	4.308	4.177	2.453	1.777	1.371
TOTAL DEPTH (cm)	3.615	3.153	2.928	2.714	3.032	5.800	4.845	10.943	10.611	6.231	4.514	3.483

ANNUAL SUMMAPY:

Sum of Mean Daily Flow 398.090 cfs = 11.274 cms
Total Depth 24.358 in = 61.869 cm
Maximum Instantaneous Flow 3.211 cfs = 0.091 cms on June 3 at 10.64 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 14
WATERSHED AREA: 389 ACRES (157 HECTARES)

WATER YEAR 1973
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.696	0.638	0.592	0.541*	0.510*	0.486*	0.500*	0.930*	0.663	0.588	0.532	0.549
2	0.690	0.638	0.590	0.538*	0.509*	0.436*	0.486*	0.915*	0.647	0.585	0.543	0.535
3	0.684	0.630	0.583	0.539*	0.509*	0.400*	0.486*	0.959*	0.652	0.575	0.566	0.519
4	0.691	0.667	0.564*	0.539*	0.508*	0.386*	0.509*	1.047*	0.640	0.576	0.552	0.514
5	0.698	0.656	0.556*	0.537*	0.505*	0.389*	0.572*	1.023*	0.637	0.577	0.546	0.509
6	0.690	0.630	0.557*	0.535*	0.502*	0.385*	0.577*	1.017*	0.632	0.571	0.546	0.502
7	0.682	0.627	0.558*	0.536*	0.503*	0.384*	0.550*	1.010*	0.628	0.569	0.539	0.547
8	0.683	0.636	0.559*	0.533*	0.505*	0.391*	0.539*	1.087*	0.630	0.566	0.539	0.551
9	0.688	0.630	0.560*	0.530*	0.504*	0.410*	0.550*	1.031*	0.638	0.564	0.539	0.532
10	0.716	0.625	0.560*	0.530*	0.504*	0.464*	0.578*	1.011*	0.639	0.559	0.545	0.522
11	0.737	0.620	0.557*	0.529*	0.504*	0.463*	0.622*	0.986*	0.637	0.561	0.543	0.517
12	0.697	0.615	0.556*	0.528*	0.502*	0.465*	0.694*	0.956*	0.637	0.560	0.538	0.510
13	0.685	0.619	0.559*	0.527*	0.499*	0.469*	0.784*	0.926*	0.652	0.560	0.529	0.506
14	0.695	0.621	0.559*	0.526*	0.498*	0.467*	0.796*	0.894*	0.859	0.562	0.529	0.546
15	0.689	0.619	0.559*	0.525*	0.498*	0.460*	0.746*	0.866*	0.702	0.559	0.529	0.548
16	0.680	0.615	0.560*	0.525*	0.495*	0.468*	0.762*	0.850*	0.685	0.559	0.525	0.538
17	0.674	0.614	0.560*	0.526*	0.491*	0.520*	0.812*	0.835*	0.740	0.554	0.519	0.534
18	0.672	0.620	0.556*	0.524*	0.487*	0.490*	0.727*	0.821*	0.695	0.553	0.517	0.530
19	0.671	0.614	0.552*	0.522*	0.481*	0.491*	0.677*	0.827*	0.668	0.599	0.511	0.578
20	0.661	0.604	0.552*	0.522*	0.478*	0.496*	0.643*	0.819*	0.646	0.665	0.512	0.608
21	0.659	0.599	0.546*	0.522*	0.474*	0.525*	0.631*	0.797*	0.636	0.606	0.526	0.554
22	0.657	0.591	0.542*	0.520*	0.470*	0.533*	0.630*	0.778*	0.621	0.580	0.524	0.542
23	0.652	0.595	0.543*	0.519*	0.468*	0.533*	0.696*	0.763*	0.611	0.564	0.536	0.561
24	0.649	0.594	0.544*	0.518*	0.465*	0.537*	0.743*	0.783*	0.604	0.556	0.534	0.580
25	0.650	0.595	0.544*	0.518*	0.462*	0.575*	0.797*	0.817*	0.607	0.551	0.554	0.561
26	0.643	0.633	0.544*	0.521*	0.459*	0.622*	0.858*	0.749*	0.606	0.543	0.547	0.533
27	0.644	0.591	0.545*	0.523*	0.457*	0.586*	0.961*	0.723*	0.598	0.540	0.534	0.526
28	0.646	0.580	0.544*	0.523*	0.458*	0.557*	0.994*	0.702*	0.596	0.534	0.527	0.519
29	0.639	0.581	0.542*	0.518*		0.533*	0.969*	0.689*	0.600	0.530	0.521	0.512
30	0.637	0.588	0.541*	0.513*		0.517*	0.953*	0.664*	0.597	0.529	0.513	0.511
31	0.633		0.542*	0.512*		0.517*		0.662		0.525	0.543	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	20.888	18.485	17.227	16.316	13.706	14.958	20.844	26.937	19.400	17.517	16.556	16.093
TOTAL FLOW (cms days)	0.592	0.523	0.488	0.462	0.388	0.424	0.590	0.763	0.549	0.496	0.469	0.456
TOTAL DEPTH (in)	1.278	1.131	1.054	0.998	0.839	0.915	1.275	1.648	1.187	1.072	1.013	0.985
TOTAL DEPTH (cm)	3.246	2.873	2.677	2.536	2.130	2.325	3.239	4.186	3.015	2.722	2.573	2.501

ANNUAL SUMMARY:
Sum of Mean Daily Flow 218.927 cfs = 6.200 cms
Total Depth 13.395 in = 34.024 cm
Maximum Instantaneous Flow 1.240 cfs = 0.035 cms on May 8 at 6.01 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 14
WATERSHED AREA: 389 ACRES (157 HECTARES)

WATER YEAR 1974
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.503	0.558	0.618	0.539*	0.702	1.028	2.007*	2.509	4.752	2.277	1.280	0.881
2	0.495	0.519	0.603	0.540*	0.689	1.007	1.797*	2.595	4.749	2.205	1.280	0.874
3	0.480	0.509	0.597	0.538*	0.678	0.926	1.670*	2.668	4.913	2.105	1.267	0.866
4	0.477	0.515	0.594	0.536*	0.675	0.866	1.494	2.725	5.227	2.047	1.241	0.856
5	0.479	0.541	0.587	0.534*	0.649	0.831	1.465	3.027	5.437	2.011	1.216	0.847
6	0.467	0.679	0.588	0.533*	0.640	0.780	1.378	3.453	5.344	1.969	1.267	0.842
7	0.514	0.570	0.684	0.533*	0.632	0.751	1.358	3.788*	5.196	1.932	1.232	0.835
8	0.496	0.611	0.652	0.534*	0.629	0.711	1.412	3.811*	4.882	1.900	1.192	0.831
9	0.489	0.692	0.643	0.534*	0.618	0.699	1.404	3.583	4.591	1.902	1.166	0.831
10	0.492	0.986	0.637	0.533*	0.611	0.703	1.380	3.732*	4.345	1.905	1.142	0.833
11	0.496	1.007	0.632	0.533*	0.609	0.749	1.362	3.738*	4.212	1.843	1.118	0.828
12	0.489	1.265	0.612	0.533*	0.614	0.818	1.346	3.530	4.173	1.768	1.093	0.829
13	0.491	0.881	0.603	0.533*	0.609	0.842	1.319	3.299	4.204	1.718	1.086	0.825
14	0.503	0.735	0.588	0.559*	0.607	0.852	1.324	3.116	4.226	1.681	1.173	0.811
15	0.491	0.703	0.582	0.915*	0.609	0.933	1.399	2.967	4.209	1.662	1.085	0.803
16	0.489	0.774	0.610	1.881*	0.617	1.459	1.508	2.835	4.075	1.619	1.056	0.793
17	0.495	0.797	0.722	2.180*	0.609	1.825	1.769	2.740	3.903	1.582	1.035	0.782
18	0.496	0.732	0.702	1.849	0.616	1.738*	2.019	2.640	3.754	1.551	1.023	0.772
19	0.491	0.670	0.701	1.750	0.615	1.567	2.190	2.583	3.594	1.522	1.062	0.760
20	0.493	0.622	0.691	1.616	0.611	1.432	2.087	2.567	3.565	1.495	1.152	0.754
21	0.499	0.607	0.695	1.477	0.618	1.315	1.987	2.509	3.324	1.473	1.058	0.749
22	0.494	0.595	0.674	1.259	0.601	1.201	2.051	2.502	3.159	1.448	1.038	0.742
23	0.503	0.585	0.652	1.112	0.597	1.128	2.425	2.572	3.011	1.431	1.014	0.732
24	0.519	0.574	0.637	1.008	0.597	1.092	2.928	2.771	2.877	1.410	0.999	0.726
25	0.561	0.567	0.626	0.939	0.596	1.117	3.402	3.108	2.759	1.388	0.979	0.724
26	0.519	0.563	0.607	0.864	0.585	1.224	3.410	3.643	2.655	1.379	0.962	0.714
27	0.513	0.567	0.614	0.814	0.587	1.528*	3.016	4.354	2.563	1.376	0.944	0.717
28	0.514	0.571	0.594	0.775	0.786	1.584*	2.681	4.804	2.483	1.349	0.932	0.720
29	0.517	0.591	0.580	0.736		2.076*	2.426	5.100	2.404	1.338	0.924	0.720
30	0.516	0.607	0.564	0.722		2.445*	2.365	5.084	2.338	1.325	0.909	0.717
31	0.613		0.550*	0.722		2.300*		4.903		1.298	0.896	

MONTHLY SUMMARY:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	15.594	20.193	19.439	28.129	17.606	37.530	58.376	103.258	116.923	51.906	33.820	23.715
TOTAL FLOW (cms days)	0.442	0.572	0.551	0.797	0.499	1.063	1.653	2.924	3.311	1.470	0.958	0.672
TOTAL DEPTH (in)	0.954	1.236	1.189	1.721	1.077	2.296	3.572	6.318	7.154	3.176	2.069	1.451
TOTAL DEPTH (cm)	2.424	3.138	3.021	4.372	2.736	5.833	9.073	16.048	18.171	8.067	5.256	3.686

ANNUAL SUMMARY:
Sum of Mean Daily Flow 526.489 cfs = 14.910 cms
Total Depth 32.214 in = 81.824 cm
Maximum Instantaneous Flow 5.529 cfs = 0.157 cms on June 5 at 5.37 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 14
WATERSHED AREA: 389 ACRES (157 HECTARES)

WATER YEAR 1975
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.737	0.647	0.599	0.582	0.539*	0.506*	0.397	0.592	1.639	1.504	1.102	0.928
2	0.730	0.640	0.598	0.588	0.540*	0.504*	0.398	0.628	1.844	1.485	1.087	0.925
3	0.732	0.636	0.601	0.589	0.539*	0.502*	0.420	0.792	1.894	1.460	1.090*	0.904
4	0.723	0.636	0.617	0.586	0.540*	0.500*	0.432	0.838	1.888	1.453	1.086*	0.894
5	0.714	0.640	0.610	0.579	0.541*	0.499*	0.435	0.772	1.909	1.440	1.074*	0.888
6	0.713	0.636	0.605	0.577	0.538*	0.500	0.435	0.742	1.969	1.427	1.062*	0.881
7	0.711	0.684	0.605	0.566	0.534*	0.501	0.433	0.766	2.038	1.413	1.123*	0.859
8	0.704	0.667	0.594	0.569	0.534*	0.535	0.432	0.838	2.089	1.395	1.056*	0.851
9	0.698	0.636	0.595	0.548	0.533*	0.559	0.433	1.033	2.103	1.371	1.045*	0.846
10	0.695	0.643	0.596	0.549	0.532*	0.545	0.437	1.229	2.080	1.359	1.030*	0.834
11	0.694	0.637	0.599	0.552	0.530*	0.517	0.455	1.412	2.034	1.345	1.015*	0.831
12	0.691	0.644	0.596	0.551	0.531*	0.491	0.493	1.397	1.978	1.351	1.007*	0.828
13	0.680	0.638	0.595	0.566	0.532*	0.480	0.531	1.551	1.936	1.350	0.988*	0.820
14	0.672	0.631	0.592	0.570	0.529*	0.472	0.553	1.865	1.896	1.307	0.986*	0.811
15	0.659	0.631	0.591	0.564	0.527*	0.470	0.580	2.317	1.869	1.297	0.985*	0.799
16	0.647	0.629	0.591	0.555	0.527*	0.473	0.593	2.362	1.841	1.289	0.970*	0.781
17	0.636	0.630	0.595	0.562	0.525*	0.463	0.598	2.101	1.881	1.282	0.996*	0.783
18	0.630	0.673	0.579	0.582	0.523*	0.491	0.602	1.919	1.860	1.284	1.049*	0.778
19	0.629	0.642	0.578	0.550	0.522*	0.496	0.600	1.764	1.863	1.265	1.171*	0.766
20	0.627	0.646	0.583	0.546	0.518*	0.491	0.615	1.630	1.830	1.245	1.101*	0.760
21	0.659	0.669	0.601	0.529	0.515*	0.485	0.631	1.546	1.782	1.229	1.009*	0.752
22	0.649	0.681	0.582	0.523	0.514*	0.485	0.653	1.400	1.746	1.218	1.005*	0.744
23	0.644	0.639	0.578	0.531	0.513*	0.473	0.663	1.330	1.740	1.201	1.191*	0.737
24	0.637	0.636	0.575	0.531	0.510*	0.473	0.676	1.283	1.738	1.186	1.067*	0.729
25	0.631	0.633	0.574	0.582	0.510*	0.473	0.734	1.208	1.664	1.168	0.999*	0.721
26	0.630	0.624	0.572	0.592	0.509*	0.457	0.683	1.164	1.668	1.148	0.962*	0.712
27	0.634	0.621	0.581	0.533	0.508*	0.442*	0.651	1.153	1.609	1.135	0.952	0.710
28	0.637	0.618	0.571	0.539	0.507*	0.429*	0.614	1.144	1.579	1.122	0.959	0.706
29	0.635	0.608	0.634	0.536		0.416*	0.598	1.152	1.555	1.118	0.936	0.700
30	0.634	0.606	0.608	0.538*		0.401	0.594	1.200	1.530	1.112	0.924	0.698
31	0.636		0.578	0.537*		0.399		1.405		1.105	0.914	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	20.750	19.199	18.377	17.303	14.720	14.927	16.368	40.529	55.049	40.063	31.940	23.975
TOTAL FLOW (cms days)	0.588	0.544	0.520	0.490	0.417	0.423	0.464	1.148	1.559	1.135	0.905	0.679
TOTAL DEPTH (in)	1.270	1.175	1.124	1.059	0.901	0.913	1.002	2.480	3.368	2.451	1.954	1.467
TOTAL DEPTH (cm)	3.225	2.984	2.856	2.689	2.288	2.320	2.544	6.299	8.555	6.226	4.964	3.726

ANNUAL SUMMARY:
Sum of Mean Daily Flow 313.201 cfs = 8.870 cms
Total Depth 19.164 in = 48.676 cm
Maximum Instantaneous Flow 2.533 cfs = 0.072 cms on May 15 at 16.50 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 14
WATERSHED AREA: 389 ACRES (157 HECTARES)

WATER YEAR 1976
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.662	0.676	0.826*	0.602*	0.759*	0.690*	0.730*	1.221*	2.191	1.365	0.981	0.724
2	0.683	0.684	0.903*	0.611*	0.774*	0.664*	0.733*	1.337*	2.133	1.351	0.951	0.723
3	0.673	0.706	0.974*	0.620*	0.785*	0.656*	0.740*	1.494*	2.091	1.336	0.937	0.720
4	0.675	0.682	1.056*	0.631*	0.779*	0.654*	0.780*	1.833*	2.036	1.326	0.935	0.714
5	0.667	0.661	0.932	0.633*	0.776*	0.624*	0.921*	1.876*	1.986	1.311	0.923	0.708
6	0.838	0.651	0.828	0.630*	0.776*	0.580*	1.069*	1.892*	1.957	1.293	0.910	0.762
7	0.844	0.656	0.890	0.630*	0.776*	0.553*	1.186*	1.923*	1.920	1.284	0.893	0.715
8	0.721	0.641	0.917	0.643*	0.776*	0.558*	1.375*	2.033*	1.906	1.273	0.936	0.707
9	0.701	0.635	0.896	0.640*	0.731*	0.562*	1.756*	2.207*	1.876	1.257	0.914	0.704
10	0.695	0.637	0.865	0.630*	0.684*	0.565*	1.839*	2.361*	1.939	1.214	0.887	0.700
11	0.728	0.627	0.818	0.640*	0.678*	0.570*	1.743*	2.771*	1.967	1.209	0.879	0.725
12	0.711	0.620	0.779	0.629*	0.681*	0.575*	1.722*	2.819*	1.916	1.243	0.877	0.731
13	0.698	0.623	0.745	0.623*	0.673*	0.578*	1.725*	2.817*	1.948	1.192	0.869	0.714
14	0.683	0.627	0.719	0.635*	0.670*	0.583*	1.697*	2.816*	1.853	1.167	0.862	0.706
15	0.676	0.769	0.709	0.691*	0.653*	0.587*	1.634*	2.813*	1.803	1.156	0.886	0.692
16	0.671	0.735	0.688	0.691*	0.659*	0.590*	1.525*	2.806*	1.752	1.142	0.877	0.708
17	0.664	0.688	0.671	0.695*	0.654*	0.595*	1.420*	2.767*	1.688	1.166	0.851	0.716
18	0.657	0.659	0.658	0.706*	0.641*	0.600*	1.376*	2.721*	1.628	1.371	0.839	0.712
19	0.651	0.638	0.651	0.703*	0.632*	0.603*	1.291*	2.690*	1.592	1.233	0.826	0.692
20	0.648	0.629	0.647	0.706*	0.626*	0.608*	1.249*	2.653*	1.624	1.155	0.812	0.679
21	0.794	0.624	0.645	0.705*	0.625*	0.613*	1.229*	2.624*	1.613	1.142	0.805	0.668
22	0.708	0.616	0.643	0.705*	0.626*	0.616*	1.220*	2.590*	1.559	1.114	0.839	0.765
23	0.669	0.616	0.639	0.706*	0.631*	0.621*	1.201*	2.568*	1.527	1.099	0.841	0.730
24	0.655	0.617	0.635	0.698*	0.630*	0.626*	1.192*	2.521*	1.505	1.139	0.813	0.708
25	0.667	0.610	0.620	0.685*	0.635*	0.629*	1.190*	2.513	1.484	1.091	0.803	0.700
26	0.747	0.599	0.649	0.685*	0.692*	0.634*	1.190*	2.432	1.467	1.058	0.802	0.684
27	0.693	0.600	0.612	0.683*	0.698*	0.638*	1.189*	2.394	1.438	1.035	0.775	0.679
28	0.678	0.595	0.600	0.691*	0.701*	0.640*	1.189*	2.415	1.418	0.995	0.767	0.671
29	0.687	0.634*	0.613	0.698*	0.696*	0.626*	1.190*	2.328	1.406	0.978	0.761	0.669
30	0.711	0.730*	0.606	0.715*		0.626*	1.190*	2.286	1.383	0.972	0.747	0.661
31	0.693		0.594	0.741*		0.661*		2.284		0.967	0.733	

MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	21.647	19.484	23.028	20.698	20.117	18.922	38.491	72.804	52.607	36.631	26.529	21.187
TOTAL FLOW (cms days)	0.613	0.552	0.652	0.586	0.570	0.536	1.090	2.062	1.490	1.037	0.751	0.600
TOTAL DEPTH (in)	1.325	1.192	1.409	1.266	1.231	1.158	2.355	4.455	3.219	2.241	1.623	1.296
TOTAL DEPTH (cm)	3.364	3.028	3.579	3.217	3.126	2.941	5.982	11.315	8.176	5.693	4.123	3.293

ANNUAL SUMMARY:
Sum of Mean Daily Flow 372.145 cfs = 10.539 cms
Total Depth 22.770 in = 57.837 cm
Maximum Instantaneous Flow 2.827 cfs = 0.080 cms on May 11 at 7.00 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 14
WATERSHED AREA: 389 ACRES (157 HECTARES)

WATER YEAR 1977
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.628	0.611	0.541	0.636	0.478	0.443	0.406	0.477	0.440	0.405	0.383	0.390
2	0.679	0.620	0.543	0.643	0.472	0.433	0.406	0.491	0.439	0.410	0.387	0.382
3	0.657	0.619	0.546	0.643	0.470	0.432	0.407	0.482	0.433	0.489	0.391	0.381
4	0.656	0.614	0.549	0.598	0.470	0.433	0.431	0.481	0.425	0.451	0.384	0.376
5	0.654	0.607	0.541	0.591	0.470	0.435	0.458	0.472	0.421	0.436	0.391	0.377
6	0.657	0.606	0.541	0.591	0.469	0.447	0.483	0.472	0.419	0.424	0.416	0.372
7	0.658	0.600	0.551	0.590	0.471	0.439	0.524	0.477	0.430	0.422	0.394	0.370
8	0.657	0.599	0.554	0.588	0.471	0.434	0.556	0.475	0.478	0.419	0.383	0.368
9	0.656	0.604	0.564	0.589	0.472	0.443	0.524	0.472	0.448	0.420	0.378	0.372
10	0.653	0.601	0.561	0.588	0.470	0.425	0.477	0.470	0.456	0.419	0.373	0.370
11	0.647	0.599	0.559	0.589	0.471	0.419	0.465	0.459	0.472	0.411	0.373	0.369
12	0.645	0.597	0.557	0.586	0.471	0.423	0.468	0.451	0.449	0.405	0.370	0.366
13	0.650	0.597	0.554	0.577	0.466	0.423	0.468	0.445	0.444	0.404	0.371	0.365
14	0.650	0.593	0.553	0.569	0.456	0.419	0.458	0.444	0.443	0.401	0.375	0.365
15	0.646	0.598	0.555	0.568	0.453	0.422	0.455	0.444	0.439	0.399	0.368	0.423
16	0.648	0.597	0.560	0.564	0.456	0.415	0.459	0.459	0.437	0.397	0.362	0.439
17	0.646	0.595	0.561	0.560	0.453	0.416	0.454	0.477	0.431	0.394	0.367	0.443
18	0.643	0.593	0.559	0.559	0.452	0.412	0.445	0.496	0.427	0.396	0.366	0.400
19	0.643	0.592	0.558	0.549	0.446	0.414	0.439	0.484	0.430	0.417	0.363	0.401
20	0.642	0.593	0.583	0.537	0.445	0.413	0.438	0.467	0.440	0.399	0.356	0.426
21	0.636	0.593	0.596	0.524	0.454	0.411	0.435	0.456	0.438	0.398	0.361	0.420
22	0.634	0.593	0.572	0.511	0.443	0.421	0.440	0.446	0.423	0.400	0.372	0.401
23	0.628	0.592	0.570	0.501	0.440	0.432	0.449	0.467	0.418	0.397	0.368	0.390
24	0.628	0.593	0.570	0.492	0.431	0.429	0.448	0.490	0.415	0.428	0.398	0.443
25	0.633	0.595	0.570	0.486	0.432	0.416	0.446	0.478	0.413	0.435	0.421	0.405
26	0.631	0.586	0.570	0.483	0.433	0.414	0.439	0.464	0.409	0.403	0.460	0.394
27	0.617	0.576	0.574	0.487	0.434	0.413	0.432	0.482	0.406	0.399	0.424	0.382
28	0.609	0.573	0.568	0.483	0.450	0.408	0.451	0.471	0.405	0.397	0.407	0.407
29	0.607	0.548	0.573	0.484		0.404	0.456	0.461	0.403	0.392	0.405	0.440
30	0.604	0.547	0.585	0.479		0.404	0.454	0.452	0.402	0.390	0.394	0.405
31	0.603		0.609	0.481		0.405		0.445		0.390	0.398	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	19.845	17.829	17.445	17.128	12.799	13.094	13.673	14.507	12.934	12.748	11.960	11.841
TOTAL FLOW (cms days)	0.562	0.505	0.494	0.485	0.362	0.371	0.387	0.411	0.366	0.361	0.339	0.335
TOTAL DEPTH (in)	1.214	1.091	1.067	1.048	0.783	0.801	0.837	0.888	0.791	0.780	0.732	0.725
TOTAL DEPTH (cm)	3.084	2.771	2.711	2.662	1.989	2.035	2.125	2.255	2.010	1.981	1.859	1.840

ANNUAL SUMMARY:
Sum of Mean Daily Flow 175.802 cfs = 4.979 cms
Total Depth 10.757 in = 27.322 cm
Maximum Instantaneous Flow 0.874 cfs = 0.025 cms on October 2 at 16.00 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 14
WATERSHED AREA: 389 ACRES (157 HECTARES)

WATER YEAR 1978
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.388	0.393	0.406*	0.392*	0.420*	0.775*	1.262*	1.291	1.704	1.405	1.076	0.844
2	0.382	0.405	0.561*	0.407*	0.419*	0.676*	1.079*	1.294	1.704	1.401	1.064	0.836
3	0.380	0.393	0.605*	0.408*	0.433*	0.584*	0.862*	1.304	1.702	1.465	1.056	0.828
4	0.374	0.389*	0.547*	0.407*	0.423*	0.499*	0.716*	1.314	1.695	1.445	1.049	0.818
5	0.373	0.401*	0.482*	0.415*	0.441*	0.422*	0.632*	1.312	1.689	1.417	1.054	0.827
6	0.375	0.393*	0.463*	0.416*	0.510*	0.347*	0.622*	1.318	1.684	1.380	1.038	0.876
7	0.393	0.389*	0.447*	0.415*	0.588*	0.330*	0.636*	1.316	1.679	1.368	1.018	0.930
8	0.378	0.380*	0.423*	0.416*	0.659*	0.404*	0.653*	1.312	1.666	1.387	1.006	0.854
9	0.375	0.378*	0.416*	0.421*	0.691*	0.600*	0.669*	1.336	1.669	1.357	0.992	0.825
10	0.380	0.380*	0.417*	0.417*	0.651*	0.699*	0.752*	1.435	1.754	1.336	0.989	0.842
11	0.388	0.379*	0.471*	0.414*	0.614*	0.655*	0.929*	1.392	1.681	1.321	0.973	0.841
12	0.388	0.384*	0.472*	0.416*	0.568*	0.584*	0.981*	1.391	1.668	1.302	0.963	0.828
13	0.387	0.387*	0.646*	0.407*	0.539*	0.510*	0.973	1.441	1.652	1.285	1.056	0.822
14	0.384	0.383*	1.433*	0.417*	0.518*	0.443*	0.978	1.459	1.650	1.271	1.015	0.804
15	0.383	0.398*	2.398*	0.418*	0.505*	0.390*	0.992	1.536	1.644	1.258	0.982	0.792
16	0.378	0.390*	1.274*	0.423*	0.487*	0.359*	1.007	1.555	1.628	1.257	1.016	0.780
17	0.378	0.377*	0.836*	0.441*	0.502*	0.370*	0.984	1.615	1.618	1.247	0.983	0.777
18	0.380	0.366*	0.670*	0.437*	0.474*	0.484*	0.980	1.652	1.619	1.235	0.960	0.799
19	0.381	0.372*	0.580*	0.442*	0.477*	0.599*	0.987	1.656	1.614	1.223	0.933	0.792
20	0.381	0.428*	0.551*	0.446*	0.480*	0.565*	1.015	1.658	1.559	1.214	0.918	0.783
21	0.381	0.380*	0.509*	0.446*	0.510*	0.622*	0.999	1.672	1.515	1.196	0.918	0.777
22	0.380	0.426*	0.489*	0.442*	0.586*	0.687*	0.990	1.701	1.504	1.182	0.952	0.765
23	0.379	0.408*	0.486*	0.422*	0.684*	0.690*	0.996	1.758	1.491	1.170	0.932	0.755
24	0.378	0.392*	0.479*	0.489*	0.744*	0.584*	0.983	1.766	1.486	1.153	0.906	0.748
25	0.465	0.463*	0.461*	0.446*	0.863*	0.426*	1.000	1.764	1.536	1.136	0.893	0.745
26	0.424	0.465*	0.448*	0.445*	0.948*	0.446*	1.093	1.749	1.484	1.124	0.887	0.741
27	0.403	0.417*	0.428*	0.431*	0.950*	0.627*	1.194	1.732	1.460	1.114	0.880	0.734
28	0.391	0.410*	0.417*	0.430*	0.868*	0.828*	1.187	1.723	1.450	1.141	0.869	0.726
29	0.385	0.417*	0.422*	0.432*		1.048*	1.210	1.702	1.427	1.132	0.863	0.725
30	0.397	0.407*	0.419*	0.420*		1.163*	1.248	1.710	1.417	1.100	0.860	0.719
31	0.396		0.406*	0.419*		1.192*		1.705		1.089	0.856	

MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	12.006	11.950	19.062	13.196	16.554	18.609	28.608	47.568	48.047	39.112	29.960	23.935
TOTAL FLOW (cms days)	0.340	0.338	0.540	0.374	0.469	0.527	0.810	1.347	1.361	1.108	0.848	0.678
TOTAL DEPTH (in)	0.735	0.731	1.166	0.807	1.013	1.139	1.750	2.911	2.940	2.393	1.833	1.464
TOTAL DEPTH (cm)	1.866	1.857	2.962	2.051	2.573	2.892	4.446	7.393	7.467	6.079	4.656	3.720

ANNUAL SUMMARY:
Sum of Mean Daily Flow 308.606 cfs = 8.740 cms
Total Depth 18.883 in = 47.962 cm
Maximum Instantaneous Flow 2.767 cfs = 0.078 cms on December 15 at 6.00 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 14
WATERSHED AREA: 389 ACRES (157 HECTARES)

WATER YEAR 1979
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.715	0.625	0.609*	0.610*	0.608*	0.610*	0.468	0.799	0.852	0.752	0.647	0.591
2	0.707	0.622	0.610*	0.610*	0.608*	0.611*	0.455	0.786	0.846	0.743	0.646	0.568
3	0.698	0.613	0.615*	0.610*	0.608*	0.611*	0.463	0.775	0.840	0.775	0.640	0.554
4	0.688	0.605	0.609*	0.610*	0.608*	0.612*	0.483	0.780	0.833	0.756	0.635	0.557
5	0.684	0.602	0.610*	0.612*	0.608*	0.611*	0.503	0.818	0.823	0.731	0.624	0.559
6	0.681	0.603	0.610*	0.611*	0.608*	0.611*	0.521	0.820	0.818	0.724	0.621	0.541
7	0.677	0.607	0.609*	0.611*	0.608*	0.608*	0.535	0.800	0.818	0.716	0.616	0.533
8	0.671	0.604*	0.610*	0.610*	0.608*	0.609*	0.604	0.800	0.816	0.698	0.619	0.526
9	0.670	0.608*	0.610*	0.606*	0.608*	0.609*	0.559	0.782	0.818	0.693	0.620	0.529
10	0.666	0.608*	0.610*	0.609*	0.608*	0.608*	0.532	0.763	0.821	0.708	0.611	0.531
11	0.659	0.610*	0.611*	0.608*	0.608*	0.606*	0.521	0.748	0.832	0.721	0.607	0.530
12	0.653	0.610*	0.612*	0.611*	0.608*	0.606*	0.514	0.739	0.828	0.723	0.629	0.530
13	0.651	0.610*	0.611*	0.609*	0.608*	0.586*	0.516	0.740	0.817	0.718	0.680	0.521
14	0.653	0.609*	0.608*	0.609*	0.609*	0.552*	0.542	0.746	0.793	0.712	0.659	0.513
15	0.652	0.610*	0.609*	0.609*	0.609*	0.523*	0.629	0.753	0.778	0.709	0.630	0.511
16	0.647	0.610*	0.608*	0.607*	0.608*	0.512*	0.754	0.762	0.779	0.705	0.620	0.508
17	0.648	0.611*	0.609*	0.610*	0.610*	0.500	0.660	0.777	0.820	0.702	0.615	0.508
18	0.645	0.611*	0.608*	0.609*	0.609*	0.495	0.608	0.804	0.963	0.696	0.616	0.504
19	0.640	0.611*	0.611*	0.608*	0.610*	0.502	0.584	0.834	0.847	0.690	0.615	0.501
20	0.631	0.609*	0.613*	0.607*	0.610*	0.508	0.616	0.842	0.812	0.680	0.602	0.499
21	0.621	0.609*	0.613*	0.607*	0.610*	0.507	0.620	0.856	0.806	0.683	0.594	0.499
22	0.621	0.609*	0.613*	0.607*	0.608*	0.509	0.650	0.861	0.795	0.778	0.588	0.497
23	0.622	0.609*	0.614*	0.606*	0.609*	0.526	0.723	0.871	0.778	0.710	0.602	0.497
24	0.619	0.610*	0.613*	0.609*	0.608*	0.515	0.713	0.885	0.775	0.692	0.616	0.494
25	0.616	0.603*	0.612*	0.609*	0.608*	0.514	0.710	0.880	0.770	0.684	0.602	0.502
26	0.619	0.603*	0.610*	0.607*	0.607*	0.581	0.723	0.881	0.764	0.670	0.600	0.513
27	0.621	0.603*	0.609*	0.607*	0.609*	0.586	0.761	0.887	0.754	0.672	0.610	0.498
28	0.621	0.602*	0.606*	0.606*	0.608*	0.552	0.787	0.896	0.749	0.674	0.606	0.493
29	0.625	0.603*	0.608*	0.608*		0.518	0.809	0.912	0.739	0.665	0.607	0.491
30	0.631	0.608*	0.605*	0.608*		0.498	0.803	0.904	0.747	0.655	0.608	0.499
31	0.626		0.610*	0.608*		0.478		0.869		0.650	0.620	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	20.177	18.260	18.913	18.868	17.034	17.272	18.366	25.368	24.231	21.885	19.206	15.597
TOTAL FLOW (cms days)	0.571	0.517	0.536	0.534	0.482	0.489	0.520	0.718	0.686	0.620	0.544	0.442
TOTAL DEPTH (in)	1.235	1.117	1.157	1.154	1.042	1.057	1.124	1.552	1.483	1.339	1.175	0.954
TOTAL DEPTH (cm)	3.136	2.838	2.939	2.932	2.647	2.684	2.854	3.943	3.766	3.401	2.985	2.424

ANNUAL SUMMARY:
Sum of Mean Daily Flow 235.178 cfs = 6.660 cms
Total Depth 14.390 in = 36.550 cm
Maximum Instantaneous Flow 1.326 cfs = 0.038 cms on June 18 at 6.00 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 14
WATERSHED AREA: 389 ACRES (157 HECTARES)

WATER YEAR 1980
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.494	0.495	0.419*	0.461*	0.440*	0.535	0.461	1.296	1.308	1.136*	0.910	0.710
2	0.498	0.494	0.416*	0.461*	0.437*	0.531	0.461	1.298	1.348	1.192*	0.890	0.731
3	0.496	0.494	0.414*	0.462*	0.434*	0.525	0.459	1.309	1.318	1.249	0.881	0.730
4	0.494	0.501	0.471	0.463*	0.430*	0.521	0.459	1.320	1.317	1.142	0.875	0.701
5	0.494	0.504	0.488	0.464*	0.426*	0.523	0.509	1.340	1.319	1.112	0.864	0.687
6	0.492	0.494	0.500	0.465*	0.421*	0.509	0.502	1.367	1.318	1.095	0.857	0.674
7	0.489	0.490	0.501	0.466*	0.416*	0.496	0.489	1.369	1.307	1.084	0.850	0.675
8	0.484	0.488	0.498*	0.466*	0.408	0.486	0.498	1.398	1.297	1.074	0.843	0.671
9	0.486	0.482	0.495*	0.469*	0.400	0.477	0.588	1.419	1.289	1.068	0.839	0.665
10	0.486	0.480	0.494*	0.468*	0.400	0.480	0.608	1.395	1.282	1.052	0.830	0.729
11	0.485	0.476	0.492*	0.471	0.403	0.483	0.629	1.362	1.273	1.045	0.818	0.737
12	0.486	0.475	0.489	0.545	0.405	0.466	0.656	1.336	1.300	1.042	0.812	0.697
13	0.484	0.476	0.491	0.659	0.405	0.472	0.732	1.321	1.294	1.033	0.808	0.762
14	0.482	0.474	0.492	0.765	0.404	0.544	0.820	1.308	1.365	1.044	0.808	0.709
15	0.583	0.473	0.495	0.742	0.402	0.553	0.890	1.354	1.298	1.026	0.807	0.678
16	0.522	0.479	0.489	0.624	0.403	0.531	0.911	1.325	1.262	1.014	0.794	0.663
17	0.529	0.498	0.493	0.586	0.410	0.515	1.001	1.278	1.240	1.002	0.785	0.652
18	0.544	0.482	0.494	0.551	0.513	0.503	1.133	1.253	1.228	1.001	0.836	0.721
19	0.611	0.470	0.491	0.532*	0.565	0.485	1.197	1.256	1.218	0.990	0.806	0.691
20	0.536	0.464	0.490	0.528*	0.575	0.488	1.263	1.245	1.226	0.981	0.787	0.667
21	0.532	0.458*	0.493	0.517*	0.555	0.496	1.252	1.235	1.210	0.968	0.775	0.660
22	0.537	0.453*	0.485	0.506*	0.513	0.496	1.236	1.261	1.204	0.958	0.770	0.650
23	0.584	0.449*	0.474	0.500*	0.484	0.496	1.241	1.310	1.228	0.947	0.760	0.639
24	0.529	0.443*	0.487	0.492*	0.464	0.488	1.318	1.262	1.192	0.941	0.745	0.635
25	0.556	0.437*	0.490	0.484*	0.461	0.480	1.276	1.314	1.167	0.941	0.743	0.627
26	0.579	0.433*	0.477	0.477*	0.480	0.477	1.228	1.317	1.160	0.935	0.740	0.618
27	0.523	0.430*	0.468	0.472*	0.523	0.471	1.208	1.287	1.151	0.927	0.746	0.623
28	0.514	0.426*	0.467	0.465*	0.556	0.465	1.245	1.270	1.137	0.923	0.736	0.623
29	0.506	0.422*	0.469	0.456*	0.543	0.474	1.307	1.293	1.129	0.912	0.731	0.624
30	0.502	0.421*	0.466	0.450*		0.463	1.312	1.281	1.126	0.906	0.722	0.633
31	0.502		0.463	0.445*		0.460		1.267		0.911	0.719	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	16.039	14.063	14.852	15.912	13.274	15.387	26.886	40.647	37.513	31.652	24.888	20.280
TOTAL FLOW (cms days)	0.454	0.398	0.421	0.451	0.376	0.436	0.761	1.151	1.062	0.896	0.705	0.574
TOTAL DEPTH (in)	0.981	0.860	0.909	0.974	0.812	0.941	1.645	2.487	2.295	1.937	1.523	1.241
TOTAL DEPTH (cm)	2.493	2.186	2.308	2.473	2.063	2.391	4.178	6.317	5.830	4.919	3.868	3.152

ANNUAL SUMMARY:
Sum of Mean Daily Flow 271.393 cfs = 7.686 cms
Total Depth 16.606 in = 42.178 cm
Maximum Instantaneous Flow 1.655 cfs = 0.047 cms on July 2 at 17.55 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 14
WATERSHED AREA: 389 ACRES (157 HECTARES)

WATER YEAR 1981
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.635	0.590	0.556	0.714	0.516	0.637	0.669	0.990	1.114	1.224	0.937	0.728
2	0.645	0.583	0.639	0.685	0.508	0.627	0.660	1.005	1.113	1.208	0.929	0.727
3	0.649	0.581	0.794	0.661	0.507	0.620	0.664	1.023	1.108	1.196	0.923	0.717
4	0.655	0.582	0.927	0.641	0.502	0.616	0.653	1.047	1.100	1.185	0.917	0.713
5	0.653	0.578	0.720	0.625	0.499	0.614	0.663	1.054	1.096	1.177	0.909	0.705
6	0.652	0.608	0.647	0.611	0.496	0.602	0.646	1.056	1.157	1.262	0.905	0.702
7	0.649	0.800	0.604	0.598	0.491	0.595	0.637	1.058	1.186	1.225	0.903	0.689
8	0.644	0.638	0.564	0.587	0.495	0.586	0.632	1.066	1.275	1.171	0.896	0.680
9	0.639	0.623	0.547	0.581	0.493	0.580	0.641	1.061	1.263	1.153	0.898	0.671
10	0.640	0.623	0.545	0.570	0.483	0.577	0.628	1.093	1.233	1.146	0.893	0.668
11	0.639	0.614	0.544	0.563	0.487	0.577	0.623	1.088	1.217	1.136	0.882	0.671
12	0.671	0.607	0.534	0.556	0.488	0.575	0.617	1.068	1.331	1.127	0.879	0.663
13	0.657	0.596	0.526	0.549	0.487*	0.574	0.606	1.053	1.308	1.113	0.867	0.656
14	0.641	0.586	0.526	0.546	0.485*	0.575	0.614	1.117	1.320	1.103	0.860	0.651
15	0.643	0.582	0.552	0.542	0.482*	0.574	0.643	1.160	1.308	1.095	0.852	0.644
16	0.639	0.577	0.557	0.541	0.653*	0.594	0.655	1.115	1.318	1.089	0.841	0.635
17	0.635	0.580	0.572	0.542	0.660	0.577	0.656	1.094	1.308	1.080	0.832	0.625
18	0.634	0.584	0.563	0.542	0.662	0.575	0.673	1.085	1.279	1.078	0.831	0.619
19	0.632	0.581	0.554	0.542	0.877	0.579	0.709	1.093	1.442	1.073	0.833	0.622
20	0.629	0.576	0.553	0.542	0.901	0.583	0.747	1.158	1.382	1.066	0.823	0.625
21	0.624	0.577	0.610	0.542	0.829	0.578	0.767	1.168	1.360	1.053	0.810	0.624
22	0.618	0.583	0.767	0.542	0.772	0.604	0.754	1.153	1.340	1.045	0.802	0.621
23	0.617	0.569	0.705	0.580	0.741	0.589	0.778	1.149	1.318	1.046	0.789	0.619
24	0.616	0.561	0.686	0.565	0.721	0.584	0.809	1.141	1.301	1.035	0.774	0.612
25	0.657	0.555	0.816	0.535	0.702	0.608	0.853	1.186	1.289	1.033	0.761	0.639
26	0.648	0.552	1.148	0.528	0.681	0.652	0.937	1.152*	1.277	1.025	0.753	0.641
27	0.621	0.554	1.117	0.531	0.660	0.627	0.991	1.122*	1.263	1.005	0.750	0.664
28	0.614	0.555	0.963	0.540	0.648	0.618	0.957	1.129	1.245	0.990	0.747	0.808
29	0.612	0.554	0.851	0.524		0.645	0.964	1.110	1.236	0.972	0.732	0.658
30	0.609	0.561	0.791	0.520		0.634	0.969	1.159	1.226	0.959	0.737	0.645
31	0.602		0.750	0.518		0.633		1.151		0.948	0.733	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	19.716	17.719	21.227	17.666	16.928	18.608	21.812	34.102	37.712	34.019	26.001	19.941
TOTAL FLOW (cms days)	0.558	0.502	0.601	0.500	0.479	0.527	0.618	0.966	1.068	0.963	0.736	0.565
TOTAL DEPTH (in)	1.206	1.084	1.299	1.081	1.036	1.139	1.335	2.087	2.307	2.082	1.591	1.220
TOTAL DEPTH (cm)	3.064	2.754	3.299	2.746	2.631	2.892	3.390	5.300	5.861	5.287	4.041	3.099

ANNUAL SUMMARY:
Sum of Mean Daily Flow 285.452 cfs = 8.084 cms
Total Depth 17.466 in = 44.363 cm
Maximum Instantaneous Flow 1.783 cfs = 0.050 cms on June 19 at 6.94 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 14
WATERSHED AREA: 389 ACRES (157 HECTARES)

WATER YEAR 1982
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.632	0.575	0.526	0.549	0.455	0.937	0.849	1.904	3.713	2.099	1.233	0.883
2	0.627	0.572	0.552	0.539	0.452	0.933	0.831	2.143	3.568	2.041	1.215	0.882
3	0.651	0.566	0.526	0.535	0.450	0.912	0.826	2.409	3.453	2.001	1.191	0.880
4	0.632	0.563	0.524	0.537	0.532	0.900	0.805	2.355	3.417	1.978	1.163	0.868
5	0.621	0.561	0.552	0.522	0.560	0.887	0.778	2.210	3.376	1.917	1.144	0.861
6	0.610	0.560	0.779	0.519	0.559	0.854	0.767	2.118	3.295	1.869	1.125	0.857
7	0.623	0.561	0.809	0.517	0.559	0.834	0.744	2.115	3.306	1.911	1.111	0.846
8	0.619	0.559	0.727	0.522	0.561	0.815	0.728	2.129	3.163	1.837	1.128	0.838
9	0.614	0.557	0.720	0.523	0.564	0.811	0.716	2.109	3.066	1.782	1.119	0.826
10	0.652	0.551	0.871	0.519	0.567	0.815	0.749*	2.081	2.966	1.740	1.083	0.855
11	0.677	0.545	0.769	0.514	0.571	0.867	1.092	2.035	2.873	1.715	1.077	0.846
12	0.631	0.608	0.691	0.500	0.565*	0.893	1.439	2.016	2.855	1.686	1.066	0.888
13	0.603	0.595	0.647	0.489	0.550*	0.898	1.592	2.051	2.848	1.665	1.040	0.876
14	0.588	0.649	0.620	0.481	0.536*	0.910	1.667	2.178	2.886	1.644	1.023	0.859
15	0.576	0.617	0.642	0.479	0.523*	0.918	1.593	2.397	2.911	1.616	1.005	0.848
16	0.573	0.731	0.615	0.477	0.830	0.916	1.438	2.653	2.879	1.584	0.990	0.837
17	0.565	0.732	0.597	0.474	0.991	0.913	1.311	2.902	2.878	1.560	0.976	0.821
18	0.557	0.643	0.590	0.467	0.961	0.904	1.200	3.064	2.874	1.532	0.965	0.810
19	0.554	0.594	0.863	0.468	1.030	0.874	1.099	2.979	2.850	1.508	0.954	0.828
20	0.548	0.574	1.282	0.464	1.567	0.832	1.042	2.878	2.808	1.485	0.955	0.896
21	0.540	0.635	1.021	0.459*	3.071	0.806	1.016	2.848	2.757	1.457	0.931	0.834
22	0.538	0.688	0.858	0.455*	3.809	0.790	1.056	2.952	2.695	1.433	0.917	0.810
23	0.536	0.629	0.754	0.451*	2.456	0.772	1.201	3.119	2.646	1.416	0.909	0.798
24	0.539	0.603	0.702	0.447*	1.762	0.765	1.441	3.291	2.572	1.407	0.905	0.791
25	0.540	0.573	0.664	0.441*	1.464	0.774	1.631	3.506	2.541	1.383	0.903	0.810
26	0.581	0.557	0.631	0.466	1.237	0.798	1.673	4.172	2.459	1.356	0.893	0.922
27	0.546	0.551	0.602	0.469	1.092	0.815	1.710	4.621	2.365	1.337	0.888	0.857
28	0.548	0.540	0.584	0.464	0.968	0.851	1.860	4.823	2.358	1.332	0.888	0.837
29	0.569	0.527	0.570	0.460		0.877	1.866	4.605	2.256*	1.304	0.914	0.866
30	0.581	0.526	0.559	0.458		0.869	1.839	4.265	2.139*	1.270	0.908	0.821
31	0.581		0.550	0.457		0.863		3.953		1.243	0.878	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	18.253	17.742	21.394	15.121	29.243	26.605	36.559	88.881	86.774	50.113	31.496	25.451
TOTAL FLOW (cms days)	0.517	0.502	0.606	0.428	0.828	0.753	1.035	2.517	2.457	1.419	0.892	0.721
TOTAL DEPTH (in)	1.117	1.086	1.309	0.925	1.789	1.628	2.237	5.438	5.309	3.066	1.927	1.557
TOTAL DEPTH (cm)	2.837	2.757	3.325	2.350	4.545	4.135	5.682	13.813	13.486	7.788	4.895	3.955

ANNUAL SUMMARY:
Sum of Mean Daily Flow 447.632 cfs = 12.677 cms
Total Depth 27.389 in = 69.568 cm
Maximum Instantaneous Flow 4.905 cfs = 0.139 cms on May 28 at 12.12 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 15
WATERSHED AREA: 355 ACRES (143 HECTARES)

WATER YEAR 1968
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.289	0.242	0.226	0.283	0.271	0.600	0.492*	0.425	0.392	0.234	0.187	0.207
2	0.366	0.236	0.229	0.276	0.292	0.588	0.491*	0.432	0.382	0.229	0.177	0.209
3	0.364	0.233	0.234	0.270	0.301	0.586	0.521*	0.439	0.428	0.226	0.179	0.212
4	0.248	0.234	0.242	0.268	0.299	0.612	0.545*	0.449	0.407	0.223	0.189	0.213
5	0.246	0.232	0.251	0.264	0.311	0.666	0.564*	0.458	0.383	0.217	0.189	0.212
6	0.242	0.234	0.233	0.254	0.322	0.709	0.591	0.457	0.391	0.216	0.184	0.209
7	0.216	0.235	0.232	0.258	0.330	0.679	0.589	0.448	0.389	0.213	0.177	0.206
8	0.214	0.236	0.230	0.259	0.327	0.642	0.572	0.431	0.368	0.209	0.175	0.206
9	0.249	0.247	0.227	0.268	0.318	0.600	0.558	0.416	0.365	0.212	0.176	0.205
10	0.247	0.276	0.227	0.292	0.312	0.547	0.566	0.417	0.331	0.237	0.180	0.198
11	0.257	0.282	0.227	0.267	0.305	0.511	0.591	0.417	0.281	0.212	0.178	0.199
12	0.303	0.260	0.223	0.265	0.299	0.487	0.577	0.443	0.273	0.222	0.174	0.212
13	0.268	0.253	0.222	0.265	0.293	0.486	0.556	0.463	0.290	0.219	0.195	0.202
14	0.261	0.254	0.220	0.265	0.288	0.466	0.537	0.461	0.285	0.213	0.231	0.235
15	0.250	0.260	0.187	0.285	0.286	0.441	0.527	0.407	0.276	0.205	0.255	0.253
16	0.252	0.247	0.190	0.292	0.280	0.438	0.504	0.383	0.271	0.204	0.216	0.236
17	0.262	0.246	0.195*	0.278	0.283	0.448	0.486	0.427	0.269	0.206	0.228	0.227
18	0.252	0.246	0.217*	0.273	0.318	0.435	0.464	0.497	0.257	0.201	0.259	0.220
19	0.251	0.244	0.237*	0.272	0.492	0.421	0.448	0.486	0.258	0.198	0.249	0.222
20	0.242	0.239	0.240	0.271	0.612	0.405*	0.440	0.516	0.260	0.195	0.259	0.243
21	0.282	0.237	0.243	0.271	0.807	0.392*	0.431	0.489	0.251	0.194	0.239	0.257
22	0.290	0.235	0.256	0.270	0.829	0.381*	0.415	0.478	0.277	0.197	0.227	0.252
23	0.279	0.235	0.278	0.266	0.865	0.369*	0.401	0.460	0.269	0.192	0.220	0.237
24	0.256	0.245	0.266	0.266	0.917	0.369*	0.399	0.456	0.252	0.191	0.206	0.229
25	0.244	0.239	0.303	0.268	0.798	0.383*	0.392	0.464	0.246	0.190	0.198	0.226
26	0.238	0.230	0.350	0.266	0.713	0.406*	0.387	0.460	0.240	0.187	0.200	0.223
27	0.251	0.242	0.309	0.265	0.670	0.427*	0.378	0.451	0.231	0.186	0.200	0.230
28	0.341	0.236	0.298	0.286	0.630	0.430*	0.378	0.444	0.229	0.188	0.209	0.230
29	0.271	0.242	0.284	0.281	0.608	0.431*	0.394	0.438	0.243	0.186	0.210	0.232
30	0.258	0.234	0.286	0.266		0.450*	0.413	0.423	0.242	0.177	0.210	0.232
31	0.249		0.288	0.270*		0.487*		0.414		0.178	0.207	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	8.237	7.311	7.649	8.401	13.375	15.293	14.606	13.848	9.037	6.358	6.383	6.673
TOTAL FLOW (cms days)	0.233	0.207	0.217	0.238	0.379	0.433	0.414	0.392	0.256	0.180	0.181	0.189
TOTAL DEPTH (in)	0.552	0.490	0.513	0.563	0.897	1.025	0.979	0.928	0.606	0.426	0.428	0.447
TOTAL DEPTH (cm)	1.403	1.245	1.303	1.431	2.278	2.604	2.487	2.358	1.539	1.083	1.087	1.136

ANNUAL SUMMARY:
Sum of Mean Daily Flow 117.171 cfs = 3.318 cms
Total Depth 7.856 in = 19.954 cm
Maximum Instantaneous Flow 0.965 cfs = 0.027 cms on February 24 at 2.75 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 15
WATERSHED AREA: 355 ACRES (143 HECTARES)

WATER YEAR 1969
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.232	0.233	0.253	0.289	0.314	0.270	0.908	0.661	0.356	0.274	0.224	0.199
2	0.229	0.232	0.252	0.260	0.307	0.278	0.980	0.632	0.366	0.266	0.227	0.195
3	0.231	0.235	0.251	0.253	0.308	0.300	1.066	0.606	0.350	0.270	0.224	0.202
4	0.232	0.238	0.252	0.258	0.308	0.317	0.998	0.584	0.352	0.268	0.219	0.207
5	0.233	0.235	0.254	0.286	0.308	0.331	1.129	0.569	0.366	0.258	0.219	0.213
6	0.227	0.233	0.251	0.316	0.303	0.337	1.338	0.560	0.361	0.260	0.225	0.213
7	0.228	0.232	0.246	0.345	0.295	0.324	1.231*	0.547	0.350	0.259	0.226	0.210
8	0.258*	0.245	0.254	0.338	0.289	0.313	1.045	0.553	0.358	0.258	0.234	0.208
9	0.298*	0.299	0.258	0.322	0.288	0.303	0.962	0.542	0.390	0.250	0.239	0.217
10	0.284*	0.259	0.278	0.311	0.286	0.305	0.960	0.537	0.362	0.251	0.239	0.200
11	0.276	0.279	0.293	0.302	0.283	0.304	0.926	0.527	0.306*	0.249	0.244	0.211
12	0.313	0.459	0.273	0.296	0.290	0.299	0.937	0.519	0.305	0.240	0.232	0.221
13	0.257	0.304	0.267	0.467*	0.287	0.308	0.980	0.518	0.302	0.240	0.201	0.216
14	0.231*	0.269	0.275	0.588*	0.281	0.315	0.945	0.526	0.287	0.243	0.182	0.215
15	0.230	0.260	0.279	0.535	0.281	0.329	0.890	0.569	0.286	0.225	0.159	0.197
16	0.237	0.258	0.280	0.467	0.282	0.344	0.852	0.506	0.278	0.211	0.154	0.195
17	0.234	0.253	0.264	0.406	0.282	0.371	0.848	0.482	0.267	0.206	0.159	0.196
18	0.238	0.264	0.262	0.363	0.279	0.403	0.886	0.471	0.260	0.204	0.157	0.205
19	0.239	0.270*	0.266	0.343	0.277	0.415	0.865	0.506	0.273	0.200	0.157	0.220
20	0.252	0.272	0.257	0.325	0.278	0.408	0.837	0.513	0.287	0.197	0.151	0.228
21	0.246	0.272	0.266*	0.563	0.285	0.416	0.814	0.471	0.275	0.203	0.155	0.187
22	0.240	0.340	0.262*	0.626	0.287	0.456	0.846	0.460	0.279	0.198	0.191	0.177
23	0.239	0.311	0.271	0.537	0.287	0.457	0.907	0.448	0.313	0.199	0.209	0.178
24	0.239	0.299	0.284	0.478*	0.287	0.433	0.927	0.435	0.310	0.203	0.212	0.178
25	0.237	0.288	0.273	0.425	0.287	0.412	0.877	0.425	0.308	0.205	0.211	0.165
26	0.227	0.276	0.265	0.422	0.281	0.439	0.818	0.416	0.295	0.206	0.211	0.164
27	0.222	0.273	0.264	0.371	0.270	0.518	0.772	0.414	0.354	0.198	0.214	0.166
28	0.223	0.264	0.262	0.347	0.271	0.555	0.737	0.403*	0.332	0.192	0.205	0.161
29	0.221	0.256	0.258	0.333		0.648	0.710	0.391*	0.307	0.197	0.205	0.172
30	0.241	0.263	0.304	0.324		0.778	0.681	0.368	0.288	0.213	0.202	0.205
31	0.238		0.293	0.317		0.902		0.358		0.223	0.203	
MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	7.532	8.172	8.267	11.814	8.078	12.587	27.671	15.517	9.526	7.069	6.291	5.920
TOTAL FLOW (cms days)	0.213	0.231	0.234	0.335	0.229	0.356	0.784	0.439	0.270	0.200	0.178	0.168
TOTAL DEPTH (in)	0.505	0.548	0.554	0.792	0.542	0.844	1.855	1.040	0.639	0.474	0.422	0.397
TOTAL DEPTH (cm)	1.283	1.392	1.408	2.012	1.376	2.144	4.712	2.643	1.622	1.204	1.071	1.008

ANNUAL SUMMARY:
Sum of Mean Daily Flow 128.444 cfs = 3.638 cms
Total Depth 8.612 in = 21.874 cm
Maximum Instantaneous Flow 1.457 cfs = 0.041 cms on April 6 at 13.75 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 15
WATERSHED AREA: 355 ACRES (143 HECTARES)

WATER YEAR 1970
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.241	0.242	0.239	0.230	0.375	0.427	0.397	0.412	0.603	0.439	0.255	0.221
2	0.281	0.241	0.233	0.230	0.350	0.419	0.398	0.444	0.573	0.406	0.255	0.219
3	0.261	0.239	0.224	0.230	0.337	0.416	0.382	0.512	0.554	0.383	0.256	0.217
4	0.260	0.235	0.224	0.230	0.316	0.417	0.381	0.619	0.536	0.367	0.253	0.302
5	0.264	0.263	0.220	0.230	0.311	0.418	0.408	0.760	0.519	0.357	0.259	0.267
6	0.263	0.269	0.216	0.230	0.313	0.421	0.472	0.827	0.504	0.354	0.255	0.255
7	0.260	0.259	0.224	0.231	0.312	0.459	0.512	0.832	0.511	0.335	0.247	0.386
8	0.274	0.248	0.226	0.234	0.298	0.462	0.491	0.793	0.522	0.325	0.243	0.332
9	0.275	0.246	0.224	0.234	0.299	0.481	0.510	0.769	0.515	0.325	0.238	0.252
10	0.267	0.246	0.224	0.233	0.317	0.495	0.638	0.755	0.504	0.328	0.239	0.245
11	0.259	0.245	0.229	0.232	0.331	0.498	0.670	0.718	0.478	0.317	0.240	0.238
12	0.249	0.242	0.313	0.236	0.375	0.488	0.637	0.689	0.479	0.312	0.237	0.228
13	0.248	0.241	0.272	0.268	0.434	0.476	0.602	0.651	0.478	0.318	0.236	0.227
14	0.252	0.240	0.263	0.304	0.462	0.510	0.572	0.618	0.521	0.312	0.238	0.231
15	0.260	0.238	0.254	0.291	0.454	0.548	0.538	0.588	0.500	0.308	0.235	0.226
16	0.264	0.239	0.244	0.279	0.457	0.571	0.508	0.592	0.483	0.305	0.231	0.220
17	0.268	0.238	0.244	0.294	0.552	0.564	0.488	0.622	0.463*	0.302	0.227	0.218
18	0.266	0.235	0.254	0.348	0.556	0.545	0.476	0.679	0.411*	0.300	0.226	0.218
19	0.262	0.239	0.272	0.408	0.526	0.515	0.478	0.723	0.380	0.296	0.230	0.256
20	0.262	0.242	0.298	0.436*	0.493	0.497	0.465	0.732	0.357	0.289	0.224	0.227
21	0.243	0.241	0.453	0.439	0.464	0.485	0.455	0.699	0.358	0.293	0.223	0.231
22	0.239	0.240	0.321	0.526	0.442	0.470	0.441	0.681	0.352	0.292	0.222	0.227
23	0.237	0.241	0.261	0.691	0.426	0.454	0.433	0.866	0.342	0.284	0.221	0.225
24	0.237	0.244	0.236	1.216	0.413	0.453	0.429	0.755	0.350	0.275	0.216	0.217
25	0.239	0.244	0.224	0.886	0.405	0.441	0.420	0.741	0.336	0.271	0.216	0.222
26	0.238	0.244	0.226	0.623	0.386	0.441	0.417	0.724	0.332	0.271	0.214	0.223
27	0.242	0.240	0.216	0.632	0.383	0.430	0.413	0.715	0.453	0.258	0.213	0.223
28	0.252	0.235	0.209	0.598	0.380	0.427	0.410	0.694	0.414	0.260	0.213	0.222
29	0.238	0.235	0.210	0.501		0.429	0.408	0.673	0.576	0.269	0.217	0.221
30	0.245	0.237	0.221	0.445		0.425	0.408	0.665	0.501	0.263	0.219	0.214
31	0.244		0.230	0.401		0.405		0.629		0.258	0.223	
MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	7.890	7.289	7.702	12.365	11.167	14.486	14.259	21.177	13.903	9.670	7.219	7.211
TOTAL FLOW (cms days)	0.223	0.206	0.218	0.350	0.316	0.410	0.404	0.600	0.394	0.274	0.204	0.204
TOTAL DEPTH (in)	0.529	0.489	0.516	0.829	0.749	0.971	0.956	1.420	0.932	0.648	0.484	0.483
TOTAL DEPTH (cm)	1.344	1.241	1.312	2.106	1.902	2.467	2.428	3.606	2.368	1.647	1.229	1.228

ANNUAL SUMMARY:
Sum of Mean Daily Flow 134.338 cfs = 3.804 cms
Total Depth 9.007 in = 22.878 cm
Maximum Instantaneous Flow 1.474 cfs = 0.042 cms on May 23 at 2.75 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 15
WATERSHED AREA: 355 ACRES (143 HECTARES)

WATER YEAR 1971
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.206	0.239	0.287	0.119	0.797	0.450	0.934*	1.374*	0.910	-----	-----	-----
2	0.203	0.236	0.293	0.134	0.796	0.463*	0.912*	1.450*	0.914	-----	-----	-----
3	0.202	0.235	0.286	0.156	0.717	0.472*	0.909*	1.642*	0.912	-----	-----	-----
4	0.201	0.236*	0.274	0.159	0.641	0.460*	0.924*	1.644*	-----	-----	-----	-----
5	0.206	0.246	0.277	0.159	0.567	0.441*	0.947*	1.646*	-----	-----	-----	-----
6	0.214	0.272	0.305	0.160	0.501	0.425*	0.996*	1.646*	-----	-----	-----	-----
7	0.217	0.276	0.372	0.161	0.458	0.427*	1.113*	1.648*	-----	-----	-----	-----
8	0.217	0.264	0.486	0.165	0.425	0.423*	1.130*	1.651*	-----	-----	-----	-----
9	0.228	0.280	0.428	0.169	0.404	0.419*	1.126*	1.651*	-----	-----	-----	-----
10	0.241	0.281	0.376	0.169	0.399	0.412*	1.164*	1.653*	-----	-----	-----	-----
11	0.229	0.275	0.346	0.167	0.395	0.419*	1.130*	1.655*	-----	-----	-----	-----
12	0.221	0.272	0.302	0.164	0.378	0.501*	1.058*	1.655*	-----	-----	-----	-----
13	0.214	0.272	0.298	0.167	0.405	0.516*	1.007*	1.657*	-----	-----	-----	-----
14	0.216	0.275	0.286	0.200	0.481	0.512*	1.035*	1.660*	-----	-----	-----	-----
15	0.216	0.273	0.256	0.236	0.579	0.514*	1.169*	1.660*	-----	-----	-----	-----
16	0.216	0.276	0.245	0.270	0.666	0.500*	1.181*	1.662*	-----	-----	-----	-----
17	0.217	0.275	0.230	0.387	0.689	0.496*	1.158*	1.664*	-----	-----	-----	-----
18	0.215	0.269	0.205	0.377	0.675	0.478*	1.099*	1.664*	-----	-----	-----	-----
19	0.216	0.264	0.208	0.466	0.639	0.474*	1.078*	1.646*	-----	-----	-----	-----
20	0.221	0.261	0.200	0.855	0.589	0.477*	1.099*	1.606*	-----	-----	-----	-----
21	0.250	0.252	0.191	0.782	0.544	0.495*	1.176*	1.446*	-----	-----	-----	-----
22	0.264	0.239	0.179	0.608	0.528	0.518*	1.207*	1.061	-----	-----	-----	-----
23	0.276	0.237	0.120	0.514	0.516	0.559*	1.226*	0.946	-----	-----	-----	-----
24	0.278	0.461	0.120	0.457	0.503	0.662*	1.242*	0.927	-----	-----	-----	-----
25	0.250	0.432	0.160	0.428	0.495	0.765*	1.214*	0.910	-----	-----	-----	-----
26	0.244	0.344	0.155	0.400	0.480	0.919*	1.153*	0.909	-----	-----	-----	-----
27	0.235	0.314	0.158	0.384	0.478	1.048*	1.125*	0.901	-----	-----	-----	-----
28	0.235	0.299	0.155	0.376	0.466	0.954*	1.138*	0.899	-----	-----	-----	-----
29	0.237	0.285	0.147	0.373		0.908*	1.195*	0.897	-----	-----	-----	0.342*
30	0.237	0.297	0.138	0.385		0.921*	1.291*	0.903	-----	-----	-----	0.322
31	0.238		0.124	0.520		0.942*		0.906		-----	-----	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	7.060	8.437	7.606	10.065	15.213	17.971	33.140	43.235	2.735	0.000	0.000	0.664
TOTAL FLOW (cms days)	0.200	0.239	0.215	0.285	0.431	0.509	0.939	1.224	0.077	0.000	0.000	0.019
TOTAL DEPTH (in)	0.473	0.566	0.510	0.675	1.020	1.205	2.222	2.899	0.183	0.000	0.000	0.045
TOTAL DEPTH (cm)	1.202	1.437	1.295	1.714	2.591	3.060	5.644	7.363	0.466	0.000	0.000	0.113

ANNUAL SUMMARY:
Sum of Mean Daily Flow 146.126 cfs = 4.138 cms
Total Depth 9.797 in = 24.885 cm
Maximum Instantaneous Flow 1.664 cfs = 0.047 cms on May 19 at 8.00 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 15
WATERSHED AREA: 355 ACRES (143 HECTARES)

WATER YEAR 1972
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.324	0.343	0.312*	0.322*	0.299*	0.818*	0.625*	0.831*	0.746	0.400	0.348	0.277
2	0.320	0.347	0.317*	0.320*	0.305*	0.618*	0.664*	0.770*	0.732	0.392	0.323	0.275
3	0.320	0.352*	0.328*	0.306*	0.312*	0.518*	0.675*	0.786*	0.732	0.369	0.325	0.269
4	0.317	0.351*	0.325*	0.307*	0.317*	0.464*	0.698*	0.862*	0.700	0.369	0.322	0.264
5	0.319	0.336	0.340*	0.307*	0.320*	0.449*	0.799*	0.941*	0.665	0.367	0.317	0.287
6	0.318	0.334	0.342*	0.325*	0.320*	0.488*	0.929*	1.087*	0.654	0.360	0.311	0.300
7	0.317	0.333	0.321*	0.350*	0.318*	0.538*	0.946*	1.144*	0.657	0.349	0.307	0.282
8	0.345	0.331	0.321*	0.337*	0.328*	0.545*	0.911*	1.202*	0.662	0.351	0.298	0.277
9	0.344	0.329	0.320*	0.341*	0.325*	0.603*	0.871*	1.092*	0.647	0.386	0.290	0.262
10	0.340	0.334	0.321*	0.335*	0.322*	0.831*	0.833*	1.003*	0.678	0.366	0.285	0.273
11	0.337	0.334	0.325*	0.344*	0.319*	1.076*	0.839*	0.927*	0.639	0.352	0.278	0.297
12	0.332	0.350	0.325*	0.332*	0.317*	1.126*	0.850*	0.880*	0.601	0.344	0.277	0.315
13	0.326	0.330	0.323*	0.323*	0.324*	1.281*	0.830*	0.906*	0.588	0.335	0.276	0.290
14	0.325	0.319	0.322*	0.322*	0.311*	1.355*	0.817*	1.064*	0.567	0.328	0.284	0.278
15	0.326	0.315	0.322*	0.323*	0.313*	1.215*	0.802*	1.299*	0.550	0.330	0.305	0.266
16	0.339	0.308	0.323*	0.325*	0.318*	1.236*	0.826*	1.466*	0.534	0.330	0.293	0.256
17	0.339	0.307	0.322*	0.342*	0.313*	1.361*	0.805*	1.586*	0.516	0.329	0.283	0.249
18	0.339*	0.307	0.321*	0.344*	0.330*	1.493*	0.804*	1.586*	0.515	0.330	0.290	0.258
19	0.340*	0.303	0.320*	0.354*	0.333*	1.379*	0.793*	1.507*	0.503	0.358	0.287	0.265
20	0.342*	0.299	0.319*	0.407*	0.385*	1.211*	0.784*	1.418*	0.510	0.351	0.282	0.260
21	0.345	0.299	0.319*	0.481*	0.381*	1.106*	0.798*	1.331*	0.516	0.371	0.271	0.251
22	0.338*	0.297	0.318*	0.393*	0.417*	1.124*	0.763*	1.270*	0.501	0.353	0.268	0.251
23	0.331*	0.296	0.318*	0.357*	0.393*	1.190*	0.773*	1.226*	0.493	0.338	0.279	0.247
24	0.332*	0.308	0.319*	0.336*	0.354*	1.090*	0.826*	1.134*	0.485	0.325	0.263	0.256
25	0.334*	0.316	0.318*	0.331*	0.327*	0.977*	0.818*	1.002*	0.496	0.319	0.262	0.257
26	0.333*	0.318*	0.318*	0.322*	0.315*	0.871*	0.786*	0.863*	0.467	0.309	0.258	0.250
27	0.334*	0.325*	0.315*	0.310*	0.462*	0.799*	0.812*	0.818	0.447	0.310	0.254	0.254
28	0.332*	0.320*	0.351*	0.307*	0.885*	0.734*	0.944*	0.797	0.430	0.302	0.284	0.242
29	0.333	0.320*	0.363*	0.303*	1.487*	0.686*	1.005*	0.789	0.414	0.291	0.280	0.247
30	0.336	0.319*	0.323*	0.300*		0.658*	0.902*	0.775	0.406	0.295	0.272	0.223
31	0.341		0.325*	0.299*		0.636*		0.762		0.332	0.274	

MONTHLY SUMMARY:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	10.299	9.681	10.058	10.406	11.450	28.475	24.526	33.124	17.051	10.638	8.945	7.978
TOTAL FLOW (cms days)	0.292	0.274	0.285	0.295	0.324	0.806	0.695	0.938	0.483	0.301	0.253	0.226
TOTAL DEPTH (in)	0.691	0.649	0.674	0.698	0.768	1.909	1.644	2.221	1.143	0.713	0.600	0.535
TOTAL DEPTH (cm)	1.754	1.649	1.713	1.772	1.950	4.849	4.177	5.641	2.904	1.812	1.523	1.359

ANNUAL SUMMARY:

Sum of Mean Daily Flow 182.632 cfs = 5.172 cms
Total Depth 12.245 in = 31.102 cm
Maximum Instantaneous Flow 1.912 cfs = 0.054 cms on February 29 at 3.30 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 15
WATERSHED AREA: 355 ACRES (143 HECTARES)

WATER YEAR 1973
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.230	0.253	0.259	0.273*	0.240	0.453	0.327	0.342	0.240	0.200	0.174	0.185
2	0.226	0.253	0.258	0.274*	0.239	0.359	0.323	0.333	0.234	0.198	0.179	0.174
3	0.221	0.248	0.250	0.272*	0.239	0.317	0.322	0.345	0.236	0.195	0.193	0.167
4	0.234	0.270	0.248*	0.273*	0.243	0.303	0.332	0.418	0.230	0.194	0.186	0.164
5	0.249	0.272	0.255*	0.276*	0.250	0.300	0.351	0.382	0.224	0.192	0.177	0.161
6	0.261	0.251	0.256*	0.277*	0.247	0.291	0.350	0.367	0.227	0.190	0.174	0.157
7	0.265	0.246	0.256*	0.277*	0.240	0.289	0.330	0.356	0.227	0.190	0.173	0.187
8	0.261	0.248	0.257*	0.278*	0.233	0.288	0.322	0.390	0.221	0.189	0.171	0.192
9	0.255	0.246	0.258*	0.277*	0.233	0.286	0.324	0.366	0.228	0.189	0.169	0.181
10	0.278	0.246	0.258*	0.276*	0.236	0.316	0.351	0.352	0.224	0.192	0.171	0.172
11	0.306	0.244	0.258*	0.275*	0.235	0.296	0.364	0.346	0.223	0.196	0.168	0.166
12	0.273	0.238	0.259*	0.273*	0.233	0.288	0.389	0.338	0.220	0.194	0.163	0.161
13	0.267	0.238	0.258*	0.271*	0.234	0.289	0.417	0.330	0.230	0.194	0.160	0.159
14	0.267	0.243	0.257*	0.269*	0.233	0.288	0.406	0.324	0.349	0.196	0.161	0.189
15	0.265	0.241	0.255*	0.278	0.234	0.284	0.372	0.318	0.271	0.190	0.160	0.190
16	0.263	0.240	0.252*	0.496	0.237	0.292	0.397	0.311	0.266	0.188	0.157	0.178
17	0.260	0.238	0.251*	0.373	0.239	0.353	0.485	0.305	0.295	0.183	0.159	0.173
18	0.251	0.241	0.254*	0.332	0.239	0.308	0.427	0.297	0.267	0.183	0.158	0.171
19	0.250	0.239	0.260*	0.298	0.238	0.307	0.398	0.297	0.246	0.217	0.157	0.211
20	0.247	0.238	0.263*	0.273	0.236	0.313	0.382	0.301	0.236	0.253	0.153	0.231
21	0.243	0.233	0.264*	0.265	0.237	0.343	0.374	0.288	0.232	0.232	0.162	0.208
22	0.243	0.234	0.266*	0.252	0.238	0.346	0.371	0.278	0.229	0.212	0.163	0.201
23	0.248	0.239	0.268*	0.247	0.243	0.356	0.390	0.271	0.226	0.202	0.163	0.210
24	0.251	0.236	0.269*	0.250	0.243	0.356	0.387	0.284	0.225	0.195	0.160	0.220
25	0.248	0.228	0.270*	0.253	0.263	0.367	0.380	0.321	0.231	0.192	0.176	0.214
26	0.247	0.258	0.271*	0.244	0.269	0.381	0.376	0.287	0.225	0.187	0.174	0.200
27	0.248	0.257	0.272*	0.235	0.309	0.363	0.377	0.273	0.223	0.184	0.167	0.197
28	0.248	0.250	0.272*	0.239	0.309	0.348	0.375	0.262	0.221	0.183	0.165	0.195
29	0.247	0.246	0.272*	0.242		0.337	0.364	0.256	0.214	0.179	0.163	0.192
30	0.245	0.250	0.272*	0.245		0.329	0.354	0.257	0.204	0.178	0.159	0.188
31	0.247		0.272*	0.244		0.333		0.258		0.174	0.178	
MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	7.846	7.362	8.090	8.608	6.869	10.080	11.115	9.852	7.126	6.042	5.193	5.593
TOTAL FLOW (cms days)	0.222	0.208	0.229	0.244	0.195	0.285	0.315	0.279	0.202	0.171	0.147	0.158
TOTAL DEPTH (in)	0.526	0.494	0.542	0.577	0.461	0.676	0.745	0.661	0.478	0.405	0.348	0.375
TOTAL DEPTH (cm)	1.336	1.254	1.378	1.466	1.170	1.717	1.893	1.678	1.214	1.029	0.884	0.952

ANNUAL SUMMARY:
Sum of Mean Daily Flow 93.774 cfs = 2.656 cms
Total Depth 6.287 in = 15.970 cm
Maximum Instantaneous Flow 0.619 cfs = 0.018 cms on January 16 at 17.53 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 15
WATERSHED AREA: 355 ACRES (143 HECTARES)

WATER YEAR 1974
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.186	0.238	0.351	0.327*	0.461*	0.708*	1.680*	1.491	1.163	0.684	0.414	0.314
2	0.184	0.210	0.372	0.329*	0.428*	0.687*	1.500*	1.542	1.146	0.679	0.417	0.314
3	0.186	0.204	0.371	0.330*	0.412*	0.621*	1.379*	1.548	1.137	0.666	0.411	0.310
4	0.188	0.206	0.358	0.332*	0.408*	0.578*	1.222*	1.513	1.137	0.642	0.395	0.303
5	0.188	0.231	0.338	0.332*	0.373*	0.543*	1.197*	1.513	1.176	0.635	0.383	0.303
6	0.183	0.378	0.329	0.332*	0.354*	0.505*	1.116*	1.591	1.213	0.631	0.426	0.302
7	0.213	0.253	0.416	0.332*	0.350*	0.478*	1.100*	1.692	1.221	0.636	0.413	0.297
8	0.195	0.290	0.435	0.332*	0.346*	0.450*	1.155*	1.757	1.164	0.626	0.391	0.290
9	0.190	0.355	0.434	0.334*	0.339*	0.441*	1.149*	1.816	1.115	0.650	0.376	0.293
10	0.190	0.658	0.420	0.337*	0.336*	0.449*	1.130*	1.801	1.070	0.666	0.368	0.299
11	0.187	0.656	0.402	0.337*	0.338*	0.489*	1.114*	1.732	1.039	0.641	0.363	0.300
12	0.185	0.920	0.369	0.338*	0.341*	0.549*	1.099*	1.625	1.026	0.597	0.358	0.307
13	0.185	0.585	0.348	0.341*	0.346*	0.573*	1.048	1.502	1.008	0.573	0.357	0.308
14	0.197	0.441	0.327	0.365*	0.347*	0.585*	1.005	1.382	0.986	0.553	0.416	0.302
15	0.191	0.422	0.311	0.731*	0.345*	0.656*	1.045	1.291	0.970	0.554	0.370	0.298
16	0.193	0.526	0.317	3.210*	0.336*	1.137*	1.152	1.196	0.949	0.537	0.360	0.292
17	0.200	0.586	0.423	3.564*	0.330*	1.467*	1.247	1.121	0.933	0.522	0.357	0.288
18	0.194	0.498	0.479	1.437*	0.337*	1.392*	1.389	1.060	0.918	0.510	0.351	0.288
19	0.193	0.418	0.492	1.334*	0.336*	1.240*	1.563	1.006	0.895	0.496	0.372	0.287
20	0.196	0.371	0.476	1.418*	0.335*	1.120*	1.570	0.985	0.978	0.488	0.435	0.286
21	0.199	0.332	0.473	1.557*	0.342*	1.013*	1.456	0.962	0.908	0.478	0.390	0.284
22	0.199	0.310	0.459	1.187*	0.332*	0.912*	1.406	0.937	0.881	0.464	0.369	0.283
23	0.203	0.295	0.447	0.955*	0.329*	0.846*	1.636	0.932	0.854	0.458	0.359	0.282
24	0.216	0.286	0.437	0.832*	0.331*	0.813*	2.082	0.939	0.826	0.452	0.355	0.280
25	0.253	0.278	0.423	0.758*	0.329*	0.840*	2.437	0.956	0.807	0.442	0.347	0.274
26	0.213	0.272	0.403	0.674*	0.325*	0.940*	2.508	0.992	0.786	0.436	0.336	0.268
27	0.207	0.267	0.399	0.597*	0.328*	1.221*	2.169	1.060	0.759	0.446	0.331	0.274
28	0.206	0.271	0.384	0.554*	0.497*	1.281*	1.836	1.110	0.740	0.438	0.327	0.271
29	0.206	0.294	0.370	0.511*		1.747*	1.642	1.159	0.723	0.429	0.327	0.268
30	0.203	0.312	0.354	0.482*		2.092*	1.493	1.199	0.705	0.428	0.325	0.266
31	0.274		0.338	0.479*		1.952*		1.185		0.420	0.316	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	6.204	11.362	12.254	24.981	10.009	28.325	43.526	40.595	29.233	16.880	11.515	8.732
TOTAL FLOW (cms days)	0.176	0.322	0.347	0.707	0.283	0.802	1.233	1.150	0.828	0.478	0.326	0.247
TOTAL DEPTH (in)	0.416	0.762	0.822	1.675	0.671	1.899	2.918	2.722	1.960	1.132	0.772	0.585
TOTAL DEPTH (cm)	1.057	1.935	2.087	4.254	1.704	4.824	7.412	6.913	4.978	2.875	1.961	1.487

ANNUAL SUMMARY:
Sum of Mean Daily Flow 243.615 cfs = 6.899 cms
Total Depth 16.334 in = 41.487 cm
Maximum Instantaneous Flow 5.163 cfs = 0.146 cms on January 17 at 1.15 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 15
WATERSHED AREA: 355 ACRES (143 HECTARES)

WATER YEAR 1975
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.272	0.267	0.266	0.254*	0.217*	0.210*	0.252*	0.485	0.994*	0.368	0.275	0.243
2	0.260	0.265	0.265	0.258*	0.218*	0.213*	0.256*	0.491	0.958*	0.364	0.274	0.251
3	0.255	0.266	0.268	0.258*	0.218*	0.216*	0.280*	0.662	0.920*	0.362	0.270	0.239
4	0.262	0.266	0.278	0.257*	0.219*	0.221*	0.293*	0.859*	0.886*	0.355	0.268	0.235
5	0.268	0.263	0.269	0.249*	0.221*	0.224*	0.302*	0.788*	0.852*	0.352	0.261	0.232
6	0.275	0.260	0.264	0.248*	0.220*	0.227*	0.306*	0.753*	0.819*	0.347	0.257	0.230
7	0.274	0.299	0.262	0.242*	0.216*	0.233*	0.308*	0.773*	0.787*	0.344	0.295	0.224
8	0.274	0.290	0.259	0.240*	0.214*	0.262*	0.313*	0.844*	0.755*	0.336	0.272	0.225
9	0.274	0.269	0.258	0.224*	0.213*	0.284*	0.317*	1.034*	0.721*	0.327	0.264	0.228
10	0.265	0.267	0.262	0.224*	0.212*	0.278*	0.326*	1.228*	0.689*	0.323	0.257	0.228
11	0.264	0.265	0.265	0.226*	0.211*	0.260*	0.347*	1.407*	0.658*	0.316	0.255	0.228
12	0.266	0.268	0.261	0.225*	0.209*	0.245*	0.386*	1.391*	0.624*	0.324	0.254	0.225
13	0.257	0.265	0.262	0.237*	0.209*	0.237*	0.426*	1.544*	0.593*	0.336	0.251	0.226
14	0.251	0.263	0.258	0.240*	0.208*	0.236*	0.452*	1.854*	0.567*	0.311	0.250	0.226
15	0.256	0.266	0.258	0.237*	0.207*	0.236*	0.483*	2.303*	0.543*	0.302	0.249	0.225
16	0.253	0.273	0.262	0.230*	0.207*	0.241*	0.503*	2.346*	0.517*	0.299	0.247	0.221
17	0.251	0.264	0.263	0.232*	0.206*	0.236*	0.515*	2.095*	0.515*	0.299	0.255	0.218
18	0.249	0.305	0.255	0.248*	0.206*	0.262*	0.523*	1.911*	0.551	0.304	0.293	0.220
19	0.254	0.273	0.255	0.225*	0.205*	0.272*	0.529*	1.754*	0.548	0.299	0.367	0.221
20	0.257	0.272	0.255	0.221*	0.203*	0.270*	0.548*	1.617*	0.546	0.288	0.338	0.221
21	0.301	0.288	0.266	0.208*	0.202*	0.266*	0.570*	1.530*	0.531	0.283	0.282	0.222
22	0.293	0.312	0.256	0.207*	0.200*	0.268*	0.597*	1.385*	0.505	0.281	0.276	0.221
23	0.289	0.287	0.255*	0.213*	0.199*	0.259*	0.610*	1.312*	0.480	0.278	0.367	0.221
24	0.277	0.286	0.267*	0.213*	0.197*	0.258*	0.625*	1.260*	0.458	0.274	0.329	0.220
25	0.271	0.282	0.272	0.251*	0.196*	0.259*	0.687*	1.186*	0.423	0.269	0.297	0.216
26	0.269	0.275	0.257	0.257*	0.198*	0.251*	0.648*	1.140*	0.424	0.267	0.271	0.212
27	0.268	0.274	0.257	0.213*	0.202*	0.247*	0.631	1.125*	0.404	0.273	0.243	0.212
28	0.266	0.275	0.256	0.216*	0.206*	0.244*	0.569	1.116*	0.395	0.271	0.252	0.212
29	0.264	0.268	0.262	0.215*		0.242*	0.536	1.108*	0.387	0.273	0.247	0.212
30	0.261	0.267	0.280	0.217*		0.239*	0.507	1.065*	0.378	0.275	0.237	0.212
31	0.264		0.268	0.216*		0.245*		1.029*		0.275	0.233	
MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	8.262	8.237	8.141	7.201	5.840	7.641	13.645	39.395	18.426	9.575	8.486	6.727
TOTAL FLOW (cms days)	0.234	0.233	0.231	0.204	0.165	0.216	0.386	1.116	0.522	0.271	0.240	0.190
TOTAL DEPTH (in)	0.554	0.552	0.546	0.483	0.392	0.512	0.915	2.641	1.235	0.642	0.569	0.451
TOTAL DEPTH (cm)	1.407	1.403	1.386	1.226	0.994	1.301	2.324	6.709	3.138	1.631	1.445	1.146

ANNUAL SUMMARY:
Sum of Mean Daily Flow 141.576 cfs = 4.009 cms
Total Depth 9.492 in = 24.110 cm
Maximum Instantaneous Flow 2.513 cfs = 0.071 cms on May 15 at 16.58 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 15
WATERSHED AREA: 355 ACRES (143 HECTARES)

WATER YEAR 1976
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.210	0.248	0.246	0.246*	0.329*	0.280*	0.384	0.892*	0.594	0.350	0.304	0.249
2	0.210	0.249	0.246	0.246*	0.338*	0.261*	0.437	1.007*	0.570	0.349	0.292	0.246
3	0.211	0.249	0.246	0.246*	0.348*	0.255*	0.462	1.150*	0.560	0.342	0.285	0.246
4	0.208	0.248	0.246	0.246*	0.343*	0.255*	0.577	1.464*	0.545	0.337	0.285	0.244
5	0.211	0.250	0.244	0.246*	0.342*	0.252*	0.788	1.503*	0.528	0.336	0.281	0.241
6	0.321	0.249	0.244*	0.246*	0.342*	0.255*	0.906	1.510*	0.522	0.333	0.275	0.290
7	0.341	0.250	0.246*	0.246*	0.342*	0.259*	0.983	1.543*	0.516	0.335	0.272	0.266
8	0.263	0.249	0.246*	0.246*	0.342*	0.263*	1.122*	1.649*	0.512	0.327	0.304	0.255
9	0.255	0.248	0.246*	0.246*	0.309*	0.267*	1.363*	1.805*	0.513	0.325	0.295	0.255
10	0.251	0.248	0.246*	0.246*	0.276*	0.271*	1.470*	1.946*	0.551	0.320	0.278	0.254
11	0.279	0.246	0.246*	0.246*	0.270*	0.275*	1.379*	2.234*	0.573	0.316	0.271	0.276
12	0.281	0.246	0.246*	0.246*	0.273*	0.279*	1.361*	2.144*	0.553	0.349	0.276	0.291
13	0.278	0.248	0.246*	0.246*	0.265*	0.284*	1.365*	2.014*	0.594	0.323	0.273	0.272
14	0.276	0.246	0.246*	0.285*	0.265*	0.288*	1.339*	1.883*	0.542	0.313	0.272	0.264
15	0.272	0.246	0.246*	0.281*	0.253*	0.292*	1.281*	1.757*	0.516	0.309	0.288	0.259
16	0.269	0.247	0.246*	0.284*	0.256*	0.296*	1.180*	1.636*	0.497	0.302	0.298	0.269
17	0.259	0.246	0.246*	0.292*	0.252*	0.301*	1.082*	1.516*	0.459	0.320	0.284	0.282
18	0.249	0.246	0.246*	0.293*	0.245*	0.305*	1.042*	1.397*	0.429	0.460	0.282	0.281
19	0.249	0.246	0.246*	0.289*	0.239*	0.309*	0.962*	1.282*	0.419	0.378	0.275	0.273
20	0.248	0.246	0.246*	0.289*	0.235*	0.313*	0.927*	1.168*	0.444	0.330	0.265	0.267
21	0.360	0.244	0.246*	0.289*	0.232*	0.318*	0.907*	1.057*	0.465	0.320	0.259	0.258
22	0.293	0.246	0.246*	0.289*	0.233*	0.322*	0.898*	0.946*	0.432	0.309	0.287	0.329
23	0.247	0.244	0.246*	0.290*	0.236*	0.326*	0.883*	0.840*	0.416	0.300	0.298	0.296
24	0.242	0.244	0.246*	0.285*	0.236*	0.331*	0.874*	0.742*	0.407	0.341	0.287	0.280
25	0.242	0.246	0.246*	0.280*	0.240*	0.335*	0.874*	0.730	0.401	0.320	0.278	0.278
26	0.242	0.245	0.246*	0.276*	0.281*	0.340*	0.874*	0.688	0.394	0.300	0.283	0.269
27	0.241	0.246	0.246*	0.273*	0.285*	0.344*	0.876*	0.665	0.383	0.292	0.266	0.262
28	0.242	0.246	0.246*	0.279*	0.288*	0.349*	0.874*	0.684	0.376	0.286	0.263	0.258
29	0.241	0.246	0.246*	0.282*	0.284*	0.352	0.876*	0.645	0.366	0.284	0.256	0.254
30	0.248	0.246	0.246*	0.294*		0.353	0.875*	0.630	0.357	0.285	0.252	0.253
31	0.248		0.246*	0.312*		0.353		0.641		0.287	0.252	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	7.987	7.402	7.619	8.359	8.180	9.283	29.222	39.770	14.433	10.075	8.635	8.014
TOTAL FLOW (cms days)	0.226	0.210	0.216	0.237	0.232	0.263	0.828	1.126	0.409	0.285	0.245	0.227
TOTAL DEPTH (in)	0.536	0.496	0.511	0.560	0.548	0.622	1.959	2.666	0.968	0.676	0.579	0.537
TOTAL DEPTH (cm)	1.360	1.261	1.297	1.424	1.393	1.581	4.977	6.773	2.458	1.716	1.471	1.365

ANNUAL SUMMARY:
Sum of Mean Daily Flow 158.981 cfs = 4.502 cms
Total Depth 10.659 in = 27.074 cm
Maximum Instantaneous Flow 2.274 cfs = 0.064 cms on May 11 at 12.00 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 15
WATERSHED AREA: 355 ACRES (143 HECTARES)

WATER YEAR 1977
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.253	0.271	0.262*	0.262*	0.258	0.239	0.234	0.255	0.211	0.163	0.144	0.151*
2	0.270	0.272	0.262*	0.262*	0.267	0.236	0.235	0.254	0.211	0.161	0.143	0.144*
3	0.274	0.272	0.262*	0.262*	0.271	0.232	0.234	0.242	0.209	0.230	0.147	0.141*
4	0.266	0.275	0.262*	0.262*	0.271	0.230	0.258	0.240	0.200	0.188	0.145	0.139*
5	0.262	0.277	0.262*	0.262*	0.270	0.228	0.279	0.232	0.190	0.179	0.147	0.140*
6	0.263	0.277	0.262*	0.262*	0.270	0.233	0.299	0.239	0.189	0.170	0.175	0.139*
7	0.262	0.277	0.262*	0.262*	0.270	0.279	0.334	0.239	0.197	0.168	0.151	0.140*
8	0.262	0.275	0.262*	0.262*	0.269	0.269	0.380	0.239	0.237	0.162	0.147	0.138*
9	0.262	0.275	0.262*	0.262*	0.265	0.280	0.362	0.237	0.216	0.159	0.146	0.140*
10	0.262	0.275	0.262*	0.262*	0.253	0.258	0.308	0.235	0.223	0.160	0.139	0.139*
11	0.262	0.276	0.262*	0.262*	0.253	0.235	0.287	0.226	0.235	0.156	0.138	0.139*
12	0.263	0.276	0.262*	0.262*	0.251	0.232	0.284	0.220	0.214	0.154	0.137	0.138*
13	0.263	0.275	0.262*	0.262*	0.252	0.234	0.283	0.213	0.205	0.154	0.136	0.137*
14	0.262	0.273	0.262*	0.262*	0.253	0.232	0.276	0.213	0.197	0.151	0.136	0.138*
15	0.261	0.272	0.262*	0.262*	0.253	0.248	0.266	0.213	0.203	0.148	0.137	0.197*
16	0.260	0.276	0.262*	0.262*	0.253	0.237	0.276	0.232	0.201	0.145	0.135	0.210*
17	0.257	0.275	0.262*	0.262*	0.251	0.236	0.276	0.249	0.197	0.144	0.135	0.212*
18	0.255	0.275	0.262*	0.262*	0.241	0.236	0.253	0.252	0.189	0.145	0.134	0.167*
19	0.256	0.275	0.262*	0.262*	0.240	0.234	0.246	0.249	0.184	0.165	0.134	0.163*
20	0.256	0.270	0.262*	0.262*	0.237	0.234	0.240	0.228	0.190	0.147	0.135	0.199*
21	0.258	0.272	0.262*	0.262*	0.249	0.232	0.241	0.219	0.187	0.149	0.135	0.203*
22	0.255	0.272	0.262*	0.262*	0.245	0.242	0.250	0.213	0.179	0.152	0.151*	0.202*
23	0.255	0.272	0.262*	0.262*	0.240	0.266	0.258	0.234	0.179	0.149	0.143*	0.188*
24	0.255	0.271	0.262*	0.258*	0.232	0.251	0.256	0.246	0.179	0.172	0.162*	0.232*
25	0.257	0.269	0.262*	0.251*	0.238	0.249	0.250	0.249	0.178	0.186	0.184*	0.207*
26	0.260	0.265	0.262*	0.246*	0.236	0.249	0.244	0.234	0.169	0.161	0.223*	0.195*
27	0.259	0.320	0.262*	0.245	0.234	0.244	0.238	0.249	0.163	0.159	0.187*	0.179*
28	0.259	0.348	0.262*	0.248	0.237	0.245	0.232	0.226	0.160	0.153	0.170*	0.183*
29	0.262	0.269	0.262*	0.249		0.245	0.234	0.221	0.159	0.151	0.167*	0.251*
30	0.265	0.263*	0.262*	0.249		0.239	0.233	0.217	0.159	0.149	0.200*	0.219*
31	0.269		0.262*	0.253		0.232		0.216		0.147	0.172*	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	8.084	8.306	8.129	8.030	7.060	7.536	8.045	7.231	5.810	4.976	4.736	5.173
TOTAL FLOW (cms days)	0.229	0.235	0.230	0.227	0.200	0.213	0.228	0.205	0.165	0.141	0.134	0.146
TOTAL DEPTH (in)	0.542	0.557	0.545	0.538	0.473	0.505	0.539	0.485	0.390	0.334	0.318	0.347
TOTAL DEPTH (cm)	1.377	1.415	1.384	1.368	1.202	1.283	1.370	1.231	0.989	0.847	0.807	0.881

ANNUAL SUMMARY:
Sum of Mean Daily Flow 83.117 cfs = 2.354 cms
Total Depth 5.573 in = 14.155 cm
Maximum Instantaneous Flow 0.473 cfs = 0.013 cms on July 3 at 11.00 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 15
WATERSHED AREA: 355 ACRES (143 HECTARES)

WATER YEAR 1978
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.192*	0.183*	0.197*	0.189*	0.206*	0.314*	1.074*	0.643	0.372	0.263	0.244	0.218
2	0.185*	0.195*	0.326*	0.198*	0.206*	0.274*	0.936*	0.643	0.358	0.267	0.243	0.216
3	0.180*	0.183*	0.361*	0.198*	0.217*	0.252*	0.728*	0.610	0.346	0.268	0.241	0.216
4	0.169*	0.182*	0.314*	0.196*	0.211*	0.235*	0.590*	0.583	0.350	0.265	0.241	0.217
5	0.165*	0.189*	0.261*	0.194*	0.222*	0.241*	0.511*	0.557	0.328	0.265	0.238	0.214
6	0.164*	0.184*	0.246*	0.194*	0.279*	0.231*	0.477*	0.549	0.315*	0.265	0.237	0.214
7	0.183*	0.181*	0.234*	0.193*	0.345*	0.243*	0.435*	0.517	0.298*	0.263	0.237	0.215
8	0.170*	0.175*	0.215*	0.194*	0.404*	0.311*	0.403*	0.491	0.293*	0.262	0.234	0.213
9	0.167*	0.174*	0.207*	0.197*	0.429*	0.492*	0.373*	0.466	0.296*	0.263	0.235	0.212
10	0.161*	0.177*	0.209*	0.203*	0.398*	0.574*	0.406*	0.498	0.344*	0.260	0.235	0.212
11	0.161*	0.176*	0.252*	0.202*	0.367*	0.543*	0.499*	0.500	0.303*	0.259	0.236	0.212
12	0.161*	0.179*	0.246*	0.199*	0.329*	0.477*	0.570*	0.477	0.295*	0.260	0.233	0.212
13	0.159*	0.182*	0.392*	0.196*	0.306*	0.406*	0.570*	0.453	0.285*	0.257	0.232	0.212
14	0.160*	0.179*	0.981*	0.202*	0.290*	0.345*	0.562*	0.454	0.283*	0.259	0.232	0.212
15	0.161*	0.194*	1.459*	0.203*	0.279*	0.298*	0.538	0.454	0.280*	0.258	0.232	0.216
16	0.160*	0.186*	0.918*	0.207*	0.263*	0.268*	0.512	0.438	0.272*	0.255	0.230	0.217
17	0.159*	0.175*	0.554*	0.221*	0.277*	0.285*	0.496	0.429	0.268*	0.257	0.229	0.218
18	0.160*	0.163*	0.413*	0.219*	0.254*	0.383*	0.476	0.430	0.269*	0.256	0.227	0.217
19	0.158*	0.169*	0.340*	0.223*	0.257*	0.491*	0.449	0.430	0.267*	0.255	0.229	0.218
20	0.154*	0.213*	0.316*	0.227*	0.259*	0.459*	0.461	0.409	0.256*	0.254	0.227	0.218
21	0.155*	0.171*	0.279*	0.228*	0.286*	0.510*	0.454	0.402	0.258	0.252	0.227	0.220
22	0.156*	0.209*	0.263*	0.227*	0.341*	0.572*	0.456	0.403	0.258	0.251	0.225	0.219
23	0.157*	0.186*	0.260*	0.215*	0.376*	0.576*	0.453	0.405	0.260	0.250	0.226	0.221
24	0.156*	0.183*	0.253*	0.264*	0.419*	0.477*	0.453	0.402	0.262	0.251	0.223	0.222
25	0.229*	0.241*	0.240*	0.228*	0.473*	0.330*	0.453	0.403	0.263	0.246	0.223	0.222
26	0.216*	0.243*	0.230*	0.228*	0.516*	0.349*	0.484	0.404	0.265	0.249	0.222	0.223
27	0.187*	0.209*	0.215*	0.217*	0.481*	0.518*	0.640	0.401	0.267	0.249	0.221	0.221
28	0.180*	0.202*	0.207*	0.214*	0.391*	0.709*	0.611	0.401	0.269	0.248	0.220	0.221
29	0.179*	0.208*	0.210*	0.214*		0.912*	0.612	0.382	0.263	0.248	0.220	0.221
30	0.188*	0.198*	0.210*	0.205*		1.018*	0.614	0.373	0.264	0.247	0.217	0.221
31	0.187*		0.200*	0.205*		1.046*		0.372		0.245	0.217	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	5.318	5.690	11.005	6.501	9.079	14.140	16.296	14.378	8.706	7.949	7.131	6.509
TOTAL FLOW (cms days)	0.151	0.161	0.312	0.184	0.257	0.400	0.461	0.407	0.247	0.225	0.202	0.184
TOTAL DEPTH (in)	0.357	0.382	0.738	0.436	0.609	0.948	1.093	0.964	0.584	0.533	0.478	0.436
TOTAL DEPTH (cm)	0.906	0.969	1.874	1.107	1.546	2.408	2.775	2.449	1.483	1.354	1.214	1.108

ANNUAL SUMMARY:
Sum of Mean Daily Flow 112.702 cfs = 3.192 cms
Total Depth 7.556 in = 19.193 cm
Maximum Instantaneous Flow 1.570 cfs = 0.044 cms on December 15 at 6.00 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 15
WATERSHED AREA: 355 ACRES (143 HECTARES)

WATER YEAR 1979
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.219	0.232	0.234	0.236	0.235	0.236	0.329	0.404	0.228	0.161	0.161	0.169
2	0.219	0.235	0.234	0.235	0.236	0.234	0.317	0.405	0.231	0.158	0.162	0.158
3	0.219	0.236	0.233	0.234	0.237	0.237	0.302	0.405	0.227	0.177	0.161	0.155
4	0.218	0.236	0.234	0.234	0.236	0.237	0.291	0.405	0.227	0.169	0.159	0.157
5	0.218	0.238	0.235	0.234	0.236	0.265	0.288	0.406	0.233	0.163	0.157	0.156
6	0.218	0.239	0.235	0.234	0.235	0.308	0.322	0.403	0.222	0.159	0.158	0.150
7	0.218	0.238	0.236	0.234	0.236	0.312	0.330	0.389	0.205	0.155	0.157	0.148
8	0.218	0.234	0.236	0.234	0.235	0.308	0.401	0.377	0.203	0.154	0.149	0.141
9	0.218	0.235	0.237	0.234	0.236	0.288	0.413	0.364	0.201	0.161	0.139	0.141
10	0.218	0.234	0.236	0.234	0.235	0.285	0.410	0.347	0.201	0.158	0.135	0.147
11	0.220	0.234	0.235	0.235	0.234	0.291	0.409	0.336	0.201	0.160	0.134	0.147
12	0.218	0.234	0.236	0.236	0.236	0.300	0.407	0.322	0.194	0.164	0.149	0.149
13	0.221	0.237	0.235	0.235	0.237	0.300	0.405	0.312	0.191	0.162	0.176	0.145
14	0.221	0.239	0.235	0.234	0.237	0.303	0.402	0.300	0.161	0.161	0.172	0.141
15	0.221	0.239	0.235	0.236	0.236	0.338	0.404	0.292	0.156	0.160	0.158	0.138
16	0.221	0.241	0.235	0.236	0.234	0.348	0.457	0.288	0.160	0.160	0.156	0.139
17	0.221	0.244	0.234	0.235	0.234	0.324	0.437	0.282	0.191	0.156	0.157	0.143
18	0.220	0.245	0.234	0.235	0.234	0.305	0.403	0.275	0.268	0.153	0.159	0.138
19	0.219	0.235	0.236	0.236	0.234	0.303	0.367	0.266	0.198	0.154	0.158	0.138
20	0.220	0.235	0.236	0.235	0.232	0.300	0.330	0.257	0.185	0.153	0.154	0.136
21	0.218	0.233	0.235	0.234	0.231	0.299	0.337	0.248	0.183	0.161	0.153	0.135
22	0.219	0.234	0.235	0.234	0.234	0.300	0.344	0.236	0.177	0.244	0.151	0.133
23	0.218	0.234	0.235	0.234	0.234	0.300	0.388	0.231	0.170	0.186	0.157	0.134
24	0.222	0.234	0.236	0.236	0.235	0.301	0.401	0.233	0.166	0.174	0.166	0.134
25	0.218	0.235	0.236	0.237	0.237	0.304	0.402	0.234	0.162	0.171	0.157	0.140
26	0.219	0.236	0.235	0.237	0.235	0.350	0.401	0.234	0.161	0.168	0.157	0.147
27	0.216	0.235	0.235	0.237	0.237	0.404	0.399	0.232	0.159	0.167	0.163	0.139
28	0.214	0.234	0.234	0.235	0.237	0.394	0.396	0.231	0.158	0.168	0.163	0.134
29	0.216	0.234	0.234	0.236		0.372	0.397	0.229	0.157	0.167	0.163	0.134
30	0.219	0.234	0.233	0.236		0.358	0.403	0.227	0.159	0.164	0.170	0.135
31	0.223		0.236	0.236		0.344		0.220		0.162	0.182	
MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	6.789	7.084	7.286	7.294	6.585	9.547	11.293	9.389	5.736	5.129	4.893	4.302
TOTAL FLOW (cms days)	0.192	0.201	0.206	0.207	0.186	0.270	0.320	0.266	0.162	0.145	0.139	0.122
TOTAL DEPTH (in)	0.455	0.475	0.488	0.489	0.441	0.640	0.757	0.629	0.385	0.344	0.328	0.288
TOTAL DEPTH (cm)	1.156	1.206	1.241	1.242	1.121	1.626	1.923	1.599	0.977	0.873	0.833	0.733

ANNUAL SUMMARY:
Sum of Mean Daily Flow 85.326 cfs = 2.416 cms
Total Depth 5.721 in = 14.531 cm
Maximum Instantaneous Flow 0.545 cfs = 0.015 cms on July 22 at 16.00 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 15
WATERSHED AREA: 355 ACRES (143 HECTARES)

WATER YEAR 1980
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.134	0.174	0.198	0.196	0.179	0.253*	0.193*	0.630*	0.355*	0.211	0.158	0.141
2	0.133	0.174	0.198	0.193	0.179	0.251*	0.194*	0.621*	0.377*	0.300	0.153	0.160
3	0.134	0.177	0.199	0.193	0.178	0.247*	0.193*	0.619*	0.351*	0.294	0.151	0.157
4	0.138	0.183	0.201	0.190	0.173	0.242*	0.193*	0.619*	0.346*	0.235	0.151	0.147
5	0.137	0.191	0.200	0.234	0.171	0.243*	0.227*	0.623*	0.337*	0.212	0.149	0.143
6	0.141	0.190	0.199	0.207	0.170	0.234*	0.216*	0.636*	0.328*	0.201	0.148	0.140
7	0.138	0.182	0.199	0.186	0.167	0.224*	0.202*	0.625*	0.315*	0.198	0.150	0.139
8	0.136	0.182	0.200	0.189	0.165*	0.216*	0.201*	0.642*	0.301*	0.197	0.148	0.135
9	0.132	0.180	0.198	0.188	0.160*	0.212*	0.263*	0.649*	0.289*	0.194	0.147	0.138
10	0.128	0.181	0.196	0.187	0.160*	0.213*	0.272*	0.623*	0.281*	0.183	0.147	0.192
11	0.131	0.181	0.198	0.190	0.162*	0.218*	0.286*	0.589*	0.269*	0.184	0.146	0.137
12	0.131	0.182	0.197	0.243	0.163*	0.204*	0.298*	0.562*	0.279*	0.185	0.144	0.119
13	0.130	0.183	0.193	0.333	0.163*	0.209*	0.349*	0.544*	0.268*	0.183	0.143	0.193
14	0.133	0.183	0.192	0.416	0.162*	0.265*	0.408*	0.523*	0.306*	0.192	0.144	0.164
15	0.195	0.186	0.193	0.398	0.159*	0.270*	0.454*	0.547*	0.269*	0.189	0.148	0.152
16	0.172	0.191	0.192	0.302	0.159*	0.254*	0.462*	0.517*	0.249*	0.179	0.147	0.146
17	0.172	0.205	0.194	0.275	0.165*	0.239*	0.522*	0.475*	0.238*	0.174	0.143	0.143
18	0.179	0.193	0.194	0.250	0.243*	0.232*	0.619*	0.448*	0.231*	0.175	0.169	0.199
19	0.212	0.187	0.192	0.242	0.283*	0.220*	0.662*	0.431*	0.226*	0.172	0.156	0.174
20	0.185	0.193	0.194	0.234	0.291*	0.222*	0.707*	0.415*	0.232*	0.171	0.155	0.172
21	0.175	0.198	0.194	0.229	0.275*	0.228*	0.688*	0.401*	0.223*	0.168	0.150	0.173
22	0.175	0.204	0.192	0.221	0.247*	0.229*	0.665*	0.411*	0.223*	0.165	0.150	0.168
23	0.190	0.207	0.188	0.213	0.224*	0.227*	0.661*	0.438*	0.238*	0.161	0.147	0.165
24	0.174	0.207	0.194	0.207	0.208*	0.221*	0.714*	0.397*	0.221*	0.162	0.145	0.160
25	0.204	0.205	0.199	0.203	0.205*	0.215*	0.675*	0.423*	0.212	0.161	0.146	0.156
26	0.207	0.204	0.192	0.197	0.220*	0.213*	0.629*	0.414*	0.209	0.161	0.145	0.151
27	0.190	0.203	0.191	0.193	0.247*	0.208*	0.608*	0.385*	0.212	0.160	0.152	0.151
28	0.188	0.201	0.224	0.187	0.270*	0.205*	0.629*	0.365*	0.207	0.159	0.146	0.149
29	0.187	0.202	0.186	0.183	0.261*	0.205*	0.670*	0.371*	0.204	0.157	0.145	0.150
30	0.180	0.198	0.186	0.181		0.195*	0.654*	0.356*	0.204	0.156	0.144	0.155
31	0.177		0.196	0.179		0.194*		0.337*		0.157	0.146	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	5.037	5.724	6.069	7.038	5.810	7.010	13.513	15.636	8.001	5.794	4.614	4.673
TOTAL FLOW (cms days)	0.143	0.162	0.172	0.199	0.165	0.199	0.383	0.443	0.227	0.164	0.131	0.132
TOTAL DEPTH (in)	0.338	0.384	0.407	0.472	0.390	0.470	0.906	1.048	0.536	0.389	0.309	0.313
TOTAL DEPTH (cm)	0.858	0.975	1.034	1.199	0.989	1.194	2.301	2.663	1.362	0.987	0.786	0.796

ANNUAL SUMMARY:
Sum of Mean Daily Flow 88.919 cfs = 2.518 cms
Total Depth 5.962 in = 15.143 cm
Maximum Instantaneous Flow 0.795 cfs = 0.023 cms on April 20 at 15.14 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 15
WATERSHED AREA: 355 ACRES (143 HECTARES)

WATER YEAR 1981
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.161	0.183*	0.189*	0.353*	0.217	0.350	0.383	0.373*	0.325	0.300	0.191	0.163
2	0.163	0.179*	0.250*	0.330*	0.214	0.343	0.387	0.372*	0.316	0.290	0.187	0.164
3	0.165	0.177*	0.367*	0.311*	0.211	0.332	0.396	0.369*	0.315	0.278	0.185	0.164
4	0.164	0.177*	0.474*	0.296*	0.209	0.326	0.395	0.373*	0.308	0.270	0.185	0.163
5	0.164	0.177*	0.318*	0.286*	0.205	0.320	0.394	0.363*	0.302	0.267	0.182	0.162
6	0.168	0.199*	0.263*	0.276*	0.206	0.310	0.387	0.349*	0.337	0.325	0.180	0.162
7	0.167	0.340*	0.235*	0.263*	0.202	0.302	0.376	0.339*	0.353	0.313	0.178	0.161
8	0.169	0.224*	0.210*	0.255*	0.204	0.295	0.366	0.330*	0.409	0.276	0.178	0.158
9	0.171	0.213*	0.198*	0.251*	0.206	0.286	0.365	0.316*	0.441	0.254	0.179	0.157
10	0.174	0.213*	0.197*	0.241*	0.211*	0.283	0.357	0.325*	0.435	0.244	0.178	0.161
11	0.176	0.209*	0.193*	0.235*	0.217*	0.279	0.353	0.309*	0.417	0.240	0.173	0.167
12	0.198	0.204*	0.187*	0.230*	0.223*	0.276	0.344	0.289*	0.487	0.236	0.171	0.165
13	0.193	0.196*	0.180*	0.225*	0.226*	0.275	0.332	0.281	0.493	0.230	0.171	0.161
14	0.184	0.188*	0.183*	0.222*	0.279	0.273	0.327	0.313	0.516	0.231	0.168	0.162
15	0.187	0.188*	0.203*	0.218*	0.231	0.269	0.329	0.345	0.509	0.227	0.167	0.161
16	0.185	0.186*	0.203*	0.222*	0.369	0.285	0.332	0.322	0.509	0.223	0.167	0.160
17	0.184	0.187*	0.201	0.231	0.403	0.279	0.327	0.310	0.489	0.221	0.166	0.160
18	0.184	0.189*	0.198	0.231	0.402	0.273	0.327	0.300	0.459	0.221	0.171	0.161
19	0.186	0.187*	0.195	0.230	0.634	0.271	0.339	0.303	0.527	0.216	0.181	0.167
20	0.186	0.185*	0.198	0.228	0.722	0.272	0.352	0.348	0.491	0.212	0.174	0.175
21	0.182	0.188*	0.246	0.225	0.612	0.271	0.365	0.374	0.475	0.209	0.169	0.175
22	0.183	0.193*	0.353	0.225	0.522	0.291	0.352	0.375	0.457	0.206	0.169	0.176
23	0.183	0.184*	0.338	0.257	0.476	0.288	0.345	0.381	0.437	0.201	0.167	0.179
24	0.185	0.180*	0.334	0.248	0.448	0.281	0.341	0.385	0.413	0.200	0.165	0.172
25	0.218	0.180*	0.537	0.229	0.421	0.292	0.357	0.412	0.390	0.204	0.163	0.191
26	0.214	0.182*	0.790*	0.225	0.399	0.336	0.398	0.404*	0.368	0.204	0.161	0.195
27	0.196	0.183*	0.682*	0.223	0.375	0.329	0.433	0.371*	0.349	0.200	0.161	0.214
28	0.187	0.185*	0.552*	0.232	0.360	0.327	0.411	0.333*	0.330	0.196	0.163	0.266
29	0.185	0.191*	0.461*	0.224		0.343	0.401*	0.334	0.320	0.191	0.159	0.180
30	0.188*	0.191*	0.413*	0.221		0.341	0.372*	0.354	0.308	0.193	0.166	0.182
31	0.192*		0.380*	0.219		0.347		0.353		0.192	0.170	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	5.642	5.859	9.728	7.662	9.401	9.349	10.941	10.704	12.285	7.271	5.346	5.180
TOTAL FLOW (cms days)	0.160	0.166	0.275	0.217	0.266	0.265	0.310	0.303	0.348	0.206	0.151	0.147
TOTAL DEPTH (in)	0.378	0.393	0.652	0.514	0.630	0.627	0.734	0.718	0.824	0.487	0.358	0.347
TOTAL DEPTH (cm)	0.961	0.998	1.657	1.305	1.601	1.592	1.863	1.823	2.092	1.238	0.910	0.882

ANNUAL SUMMARY:
Sum of Mean Daily Flow 99.368 cfs = 2.814 cms
Total Depth 6.662 in = 16.922 cm
Maximum Instantaneous Flow 0.879 cfs = 0.025 cms on December 26 at 7.60 hours

* Indicates some data were estimated during this day.

TAILHOLT CREEK STUDY AREA
WATERSHED: 15
WATERSHED AREA: 355 ACRES (143 HECTARES)

WATER YEAR 1982
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.185	0.213	0.207	0.287	0.233	0.823*	0.536	1.398	0.894	0.552	0.351	-----
2	0.189	0.211	0.242	0.282	0.232	0.747*	0.512	1.522	0.883	0.542	0.350	-----
3	0.203	0.209	0.216	0.275	0.230	0.673*	0.512	1.652	0.869	0.543	0.344	-----
4	0.192	0.208	0.214	0.274	0.227*	0.603*	0.491	1.593	0.867	0.541	0.337	-----
5	0.192	0.208	0.244	0.258	0.227*	0.574	0.472	1.451	0.870	0.530	0.332	-----
6	0.190	0.208	0.463	0.251	0.228*	0.550	0.461	1.327	0.847	0.509	0.325	-----
7	0.209	0.208	0.500	0.254	0.230*	0.546	0.450	1.269	0.865	0.559	0.322	-----
8	0.201	0.208	0.416	0.260	0.232*	0.532	0.434	1.250	0.847	0.541	0.343	-----
9	0.203	0.208	0.408	0.260	0.233*	0.534	0.430	1.203	0.811	0.516	0.343	-----
10	0.232	0.207	0.587	0.259	0.235*	0.555	0.443	1.157	0.783	0.492	0.326	-----
11	0.256	0.207	0.511	0.255	0.238*	0.629	0.737*	1.089	0.758	0.484	0.326	-----
12	0.225	0.248	0.429	0.251	0.242*	0.692	1.351	1.051	0.739	0.471	0.322	-----
13	0.213	0.244	0.380	0.246	0.251*	0.685	1.663	1.026	0.723	0.464	0.311	-----
14	0.210	0.281	0.349	0.241	0.365	0.679	1.795	1.034	0.709	0.458	0.305	-----
15	0.208	0.270	0.358	0.238	0.445	0.682	1.660	1.064	0.688	0.449	0.300	-----
16	0.204	0.349	0.338	0.238	0.854	0.660	1.431	1.095	0.666	0.442	0.294	-----
17	0.201	0.358	0.323	0.238	1.079	0.641	1.240	1.114	0.647	0.436	0.290	-----
18	0.199	0.297	0.313	0.238	1.007	0.633	1.081	1.134	0.628	0.431	0.287	-----
19	0.198	0.255	0.538	0.236	1.007	0.602	0.952	1.076	0.612	0.422	0.285	-----
20	0.200	0.231	1.088	0.232	1.608	0.568	0.870	1.020	0.594	0.415	0.286	-----
21	0.201	0.262	0.813	0.227	3.493	0.539	0.813	0.978	0.587	0.406	0.275	-----
22	0.201	0.323	0.605	0.224	4.142	0.516	0.828	0.963	0.583	0.404	0.267	-----
23	0.208	0.285	0.507	0.228	2.267	0.494	0.954	0.942	0.588	0.401	0.161	-----
24	0.210	0.261	0.451	0.235	1.631	0.487	1.136	0.916	0.580	0.400	-----	-----
25	0.210	0.236	0.413	0.233	1.246	0.498	1.252	0.904	0.599	0.394	-----	-----
26	0.239	0.218	0.383	0.242	1.067*	0.541	1.281	1.074	0.576	0.387	-----	-----
27	0.221	0.213	0.352	0.239	0.977*	0.568	1.324	0.985	0.568	0.381	-----	-----
28	0.221	0.208	0.331	0.234	0.901*	0.604	1.421	1.003	0.606	0.381	-----	-----
29	0.222	0.201	0.312	0.233		0.596	1.431	0.982	0.577	0.375	-----	-----
30	0.217	0.204	0.301	0.234		0.570	1.396	0.946	0.554	0.365	-----	-----
31	0.216		0.287	0.233		0.559		0.912		0.356	-----	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	6.473	7.240	12.879	7.635	25.127	18.577	29.355	35.129	21.115	14.049	7.082	0.000
TOTAL FLOW (cms days)	0.183	0.205	0.365	0.216	0.712	0.526	0.831	0.995	0.598	0.398	0.201	0.000
TOTAL DEPTH (in)	0.434	0.485	0.863	0.512	1.685	1.246	1.968	2.355	1.416	0.942	0.475	0.000
TOTAL DEPTH (cm)	1.102	1.233	2.193	1.300	4.279	3.164	4.999	5.982	3.596	2.393	1.206	0.000

ANNUAL SUMMARY:
Sum of Mean Daily Flow 184.661 cfs = 5.230 cms
Total Depth 12.381 in = 31.448 cm
Maximum Instantaneous Flow 5.265 cfs = 0.149 cms on February 22 at 3.24 hours

* Indicates some data were estimated during this day.
Summaries exclude missing data.

HORSE CREEK STUDY AREA
WATERSHED: 200
WATERSHED AREA: 4169 ACRES (1687 HECTARES)

WATER YEAR 1966
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	3.674	3.409	8.770	4.487	2.649	2.391	4.875*	14.451	11.864	7.140	2.288	1.783
2	3.636	3.381	4.644	4.420	2.648	2.392	5.057*	17.053	12.955	7.165	2.241	1.745
3	3.589	3.363	4.465	4.310	2.648	2.392	5.128*	18.573	11.548	7.086	2.238	1.713
4	3.575	5.363	4.564	4.251	2.648	2.392	5.199*	20.368	10.850	6.969	2.194	1.663
5	4.200	4.450	4.505	4.152	2.648	2.392	5.203	19.079	10.472	6.887	2.206	1.622
6	3.779	4.151	4.388	3.492	2.617	2.392	5.516	21.470	10.613	6.893	2.172	1.577
7	3.668	4.051	4.254	3.555	2.607	2.392	6.783	23.561	10.579	5.166	2.166	1.547
8	3.595	3.963	4.151	3.276	2.607	2.392	8.153	22.113	10.390	3.922	2.130	1.536
9	3.515	4.083	4.048	3.433	2.609	2.392	9.687	18.999	11.511	3.900	2.084	1.508
10	3.492	4.281	4.069	3.443	2.408	2.433	10.867	17.177	12.506	3.905	2.058	1.488
11	3.453	4.416	3.986	3.308	2.447	2.531	11.739	18.184	11.936	3.812	1.981	1.501
12	3.379	4.207	3.905	3.090	2.759	2.564	11.931	20.842	11.143	3.735	1.937	1.693
13	3.532	4.197	3.856	2.873	2.913	2.705	12.011	19.093	10.381	3.543	1.969	1.755
14	4.029	5.526	3.506	2.401	2.913	2.769	12.198	17.842	9.998	3.373	2.075	2.968
15	5.365	5.021	5.834	2.283	2.913	2.769	14.095	16.533	9.662	3.223	2.008	3.300
16	4.178	4.536	10.061	2.333	2.913	2.769	18.817	16.105	9.399	2.984	1.940	1.979
17	3.967	4.817	11.820	2.308	2.929	2.769	18.504	14.456	9.020	2.875	1.915	1.809
18	3.945	5.444	12.777	2.311	2.783	2.867	16.604	14.014	8.531	2.856	1.884	1.717
19	4.225*	4.823	12.788	2.508	2.739	2.901	14.709	14.121	8.450	2.834	1.816	2.079
20	3.951*	4.588	12.788	2.548	2.639	2.913	13.417	14.752	11.848	2.821	1.787	1.934
21	3.847*	4.662	12.788	2.548	2.328	2.905*	12.761	15.446	9.377	2.821	1.777	1.737
22	3.748*	4.488	9.746	2.548	2.480	2.922*	12.350	15.035	8.731	2.768	1.766	1.657
23	3.725	4.502	2.542	2.527	2.497	3.099*	12.378	14.068	8.860	2.720	1.739	1.611
24	3.657	4.119	3.707	2.367	2.509	3.302*	13.102	13.573	13.528	2.669	1.722	1.579
25	3.576	3.749	4.826	2.373	2.497	3.479*	14.393	13.676	9.719	2.611	1.718	1.568
26	3.531	3.674	4.868	2.365	2.476	3.668*	13.578	13.503	9.011	2.610	3.134	1.590
27	3.502	3.963	4.853	2.353	2.450	3.863*	13.244	13.232	8.389	2.565	3.172	1.574
28	3.566	4.254	4.664	2.446	2.435	4.075*	12.964	12.790	7.858	2.498	2.679	1.531
29	3.509	12.808	4.500	2.659		4.259*	12.685	13.066	7.642	2.445	2.243	1.500
30	3.471	16.865	4.399	2.634		4.480*	12.917	12.577	7.268	2.401	2.262	1.462
31	3.452		4.451	2.650		4.622*		12.255		2.340	1.903	

MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	116.330	151.153	190.521	92.250	73.710	92.189	340.865	508.006	304.035	119.536	65.204	52.726
TOTAL FLOW (cms days)	3.294	4.281	5.396	2.613	2.087	2.611	9.653	14.387	8.610	3.385	1.847	1.493
TOTAL DEPTH (in)	0.664	0.863	1.088	0.527	0.421	0.526	1.946	2.900	1.736	0.682	0.372	0.301
TOTAL DEPTH (cm)	1.687	2.192	2.763	1.338	1.069	1.337	4.943	7.367	4.409	1.733	0.946	0.765

ANNUAL SUMMARY:
Sum of Mean Daily Flow 2106.523 cfs = 59.657 cms
Total Depth 12.027 in = 30.547 cm
Maximum Instantaneous Flow 26.440 cfs = 0.749 cms on May 7 at 3.30 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 200
WATERSHED AREA: 4169 ACRES (1687 HECTARES)

WATER YEAR 1967
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	1.485	2.800	4.987	2.810	3.671	3.071	3.518	6.676	-----	9.410*	4.161	2.532
2	5.195	2.754	4.064	2.810	3.568	3.018	3.495	6.536	-----	8.957	3.949	2.484
3	2.252	2.634	3.532	2.780	3.621	2.893	3.812	6.935	-----	8.707	3.822	2.523
4	1.922	2.617	3.176	2.793	4.184	4.441	3.975	7.324	-----	8.300	3.772	2.513
5	1.886	2.810	3.061	2.700	4.027	5.053	3.882	-----	-----	7.954	3.700	2.482
6	1.980	3.069	2.291	2.942	3.704	5.165	4.140	-----	-----	7.673	3.565	2.529
7	2.242	2.823	2.273	2.540	3.602	4.981	4.429	-----	-----	7.396	3.593	2.516
8	2.587	2.461	2.181	2.669	3.355	3.303	4.526	-----	-----	7.190	3.550	2.724
9	2.394	2.234	5.990	2.670*	3.462	3.581	4.825	-----	-----	6.954	3.532	2.823
10	2.266	2.734	5.880	2.648*	3.493	2.785	5.260	-----	-----	6.700	3.431	2.684
11	2.247	2.411	2.838	2.648*	3.409	2.786	5.682	-----	-----	6.500	3.352	4.158
12	3.042	4.101	2.681	2.648*	3.282	2.773	6.007	-----	-----	6.323	3.275	3.512
13	2.538	4.178	4.213	2.648*	3.346	2.810	6.116	-----	-----	6.183	3.199	2.927
14	2.406	4.585	3.718	2.648*	3.218	2.816	5.816	-----	-----	6.003	3.165	2.787
15	2.411	3.931	2.669	2.648*	3.151	2.786	5.655	-----	-----	5.746	3.101	2.702
16	2.355	4.598	3.263	2.648*	3.052	3.236	5.469	-----	-----	5.606	3.043	2.601
17	2.411	3.572	2.969	2.648*	3.162	4.688	5.871	-----	-----	5.613	2.983	2.546
18	2.330	3.153	3.143	2.648*	3.149	3.668	6.478	-----	-----	5.444	2.946	2.496
19	2.272	2.991	3.261	2.648*	2.937	3.386	5.925	-----	-----	5.350	2.913	2.487
20	2.358	3.086	3.600	2.648*	7.462	3.275	5.682	-----	-----	5.160	2.933	2.458
21	2.556	3.185	3.094	2.648*	7.015	3.326	5.682	-----	-----	5.043	3.007	2.435
22	2.574	2.875	5.759	2.646*	4.718	3.451	5.898	-----	-----	4.934	2.907	2.391
23	4.031	2.740	17.044	10.739	3.032	3.769	6.144	-----	-----	4.774	2.837	2.385
24	3.560	2.653	16.032	15.791	2.959	3.783	6.506	-----	-----	4.637	2.774	2.365
25	3.426	2.337	12.854	8.502	3.018	3.641	7.079	30.941*	-----	4.517	2.739	2.314
26	3.674	1.944	10.588	3.557	2.980	3.607	7.313	36.631	-----	4.410	2.727	2.318
27	5.196	2.104	7.340	3.612	2.963	3.562	7.670	34.004	-----	4.341	2.700	2.288
28	3.204	2.574	3.676	4.293	3.018	3.562	7.610	33.724	-----	4.250	2.717	2.259
29	2.797	3.308	2.984	4.455		3.495	7.225	32.237	-----	4.210	2.653	2.294
30	4.595	3.975	2.737	4.198		3.451	6.905	29.885	-----	4.106	2.592	4.435
31	3.115		2.824	3.839		3.429		29.727*		4.498	2.580	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	87.305	91.236	154.720	118.117	102.554	109.589	168.592	254.618	0.000	186.889	98.219	79.965
TOTAL FLOW (cms days)	2.472	2.584	4.382	3.345	2.904	3.104	4.775	7.211	0.000	5.293	2.782	2.265
TOTAL DEPTH (in)	0.498	0.521	0.883	0.674	0.586	0.626	0.963	1.454	0.000	1.067	0.561	0.457
TOTAL DEPTH (cm)	1.266	1.323	2.244	1.713	1.487	1.589	2.445	3.692	0.000	2.710	1.424	1.160

ANNUAL SUMMARY:
Sum of Mean Daily Flow 1451.804 cfs = 41.115 cms
Total Depth 8.289 in = 21.053 cm
Maximum Instantaneous Flow 41.180 cfs = 1.166 cms on May 25 at 7.30 hours

* Indicates some data were estimated during this day.
Summaries exclude missing data.

HORSE CREEK STUDY AREA
WATERSHED: 200
WATERSHED AREA: 4169 ACRES (1687 HECTARES)

WATER YEAR 1968
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	3.556	6.240	3.602	5.107	3.571	-----	14.864	18.728	20.574	7.682	3.524	3.407
2	-----	3.978	3.287	4.363	3.359	-----	14.950	19.490	20.426	7.147	3.507	3.810
3	-----	3.599	2.936	10.994	3.449	-----	13.925	20.973	22.548	6.721	3.585	3.662
4	-----	2.954	2.912	13.844	3.383	-----	13.452	22.953	18.897	6.498	4.028	3.354
5	-----	2.997	2.920	11.857	3.514	-----	13.670	22.987	17.675	6.304	3.593	3.199
6	1.954	3.317	2.776	12.659	3.302	-----	12.649	20.945	17.348	6.133	3.393	3.205
7	2.583	3.644	2.788	20.057	3.244	-----	12.243	20.050	17.382	6.026	3.337	3.121
8	2.483	3.331	2.769	14.998	3.254	-----	11.715	19.830	16.422	5.905	3.265	3.054
9	2.444	3.642	2.721	7.837	3.328	-----	11.726	21.078	16.502	6.617	3.177	2.995
10	2.411	5.976	2.810	3.993	3.624	-----	13.006	23.317	15.156	6.017	3.190	2.969
11	5.265	7.717	3.433	3.586	4.174	-----	14.499	24.383	14.557	5.833	3.171	2.987
12	4.540	5.577	3.289	4.052	3.964	-----	14.157	25.731	14.574	6.408	3.139	3.153
13	4.281	4.562	12.500	4.029	3.657	-----	14.335	27.222	15.237	5.985	3.490	3.011
14	5.124	4.862	8.865	3.570	3.766	-----	14.113	28.033	13.424	5.707	5.125	4.859
15	3.585	5.166	6.054	3.715	3.766	-----	13.907	27.708	12.350	5.482	6.243	7.361
16	3.015	4.101	8.478	3.592	3.766	-----	13.115	26.161	11.681	5.310	4.094	9.346
17	2.839	3.778	8.557	3.388	3.766	-----	12.287	26.161	11.251	5.162	6.236	5.892
18	2.785	3.634	8.557	3.302	3.772	-----	11.907	26.756	8.849	4.898	6.183	6.759
19	2.938	3.531	8.557	3.272	3.812	-----	11.463	27.196	10.493	4.881	5.545	5.847
20	2.784	3.344	8.557	3.270	10.650	-----	10.670	27.925	11.007	5.365	5.196	6.279
21	3.218	3.263	8.557	4.537	21.288	-----	10.185	28.050	9.843	4.724	4.868	6.230
22	4.673	3.209	8.472	4.292	19.576	-----	9.879	26.834	11.149	4.487	4.111	6.369
23	6.528	3.247	8.342	3.830	20.740	-----	9.609	25.236	11.272	4.369	3.761	6.724
24	3.761	3.198	8.330	3.747	19.590	-----	9.522	24.054	9.549	4.272	3.572	5.836
25	3.836	4.241	10.243	3.769	17.931*	-----	9.371	25.448	8.950	4.137	3.410	5.233
26	3.403	10.037	29.395	5.514	-----	-----	9.586	25.770	8.668	4.032	3.375	4.686
27	6.556	14.523	11.476	13.683	0.267	-----	9.564	25.302	8.242	3.953	3.422	4.372
28	12.559	8.753	8.949	18.402	-----	-----	10.796	24.410	8.025	3.863	8.494	4.132
29	5.178	5.498	7.276	11.840	-----	-----	13.960	23.655	9.081	3.768	4.358	4.008
30	4.652	3.952	6.299	4.837		-----	17.389	21.880	8.506	3.606	3.794	3.829
31	4.243		5.594	4.200		-----		21.289		3.570	3.538	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	111.192	145.868	219.300	220.137	178.513	0.000	372.513	749.556	399.639	164.859	129.722	139.688
TOTAL FLOW (cms days)	3.149	4.131	6.211	6.234	5.055	0.000	10.550	21.227	11.318	4.669	3.674	3.956
TOTAL DEPTH (in)	0.635	0.833	1.252	1.257	1.019	0.000	2.127	4.279	2.282	0.941	0.741	0.798
TOTAL DEPTH (cm)	1.612	2.115	3.180	3.192	2.589	0.000	5.402	10.870	5.795	2.391	1.881	2.026

ANNUAL SUMMARY:
Sum of Mean Daily Flow 2830.985 cfs = 80.173 cms
Total Depth 16.163 in = 41.053 cm
Maximum Instantaneous Flow 54.940 cfs = 1.556 cms on December 26 at 19.00 hours

* Indicates some data were estimated during this day.
Summaries exclude missing data.

HORSE CREEK STUDY AREA
WATERSHED: 200
WATERSHED AREA: 4169 ACRES (1687 HECTARES)

WATER YEAR 1969
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	3.706	4.815	-----	-----	-----	-----	11.750	24.760	18.183	10.133	4.430	3.050
2	3.533	4.660	-----	-----	-----	-----	13.483	23.399	17.040	10.263	4.337	2.981
3	3.419	4.798	-----	-----	-----	-----	14.684	22.219	16.065	10.152	4.205	2.905
4	3.383	4.731	-----	-----	-----	-----	15.332	22.639	15.244	9.203	4.085	2.867
5	3.353	4.461	-----	-----	-----	-----	16.983	23.922	15.028	8.841	4.018	2.857
6	3.315	4.182	-----	-----	-----	-----	18.188	26.621	14.018	8.527	3.910	2.800
7	3.597	4.120	-----	-----	-----	-----	17.765	31.103	13.607	8.241	3.781	2.720
8	3.486	5.302	-----	-----	-----	-----	17.312	34.198	12.659	8.025	3.697	2.732
9	3.359	12.145	-----	-----	-----	-----	17.984	36.452	13.667	7.719	3.659	2.608
10	3.481	6.407	-----	-----	-----	-----	18.140	38.447	12.307	7.452	3.717	2.671
11	3.667	6.704	-----	-----	-----	-----	18.290	39.662	11.602	7.160	3.672	3.027
12	7.280	7.663	-----	-----	-----	-----	19.655	39.749	11.334	7.033	3.641	2.757
13	6.669	6.423	-----	-----	-----	-----	20.522	39.854	10.742	6.885	3.597	2.715
14	5.504	6.049	-----	-----	-----	-----	20.399	39.496	10.256	6.626	3.506	2.643
15	5.568	5.895	-----	-----	-----	-----	19.874	38.464	9.791	6.400	3.516	2.608
16	5.036	6.326	-----	-----	-----	-----	20.205	35.390	9.435	6.232	3.433	2.568
17	4.593	7.205	-----	-----	-----	-----	21.221	34.332	9.120	6.087	3.367	2.568
18	4.711	5.878	-----	-----	-----	-----	22.868	33.902	8.855	5.931	3.317	2.568
19	4.437	6.365	-----	-----	-----	-----	23.104	33.877	8.626	5.757	3.257	3.121
20	6.167	6.160	-----	-----	-----	-----	23.608	32.243	9.357	5.585	3.187	3.979
21	5.804	6.105	-----	-----	-----	-----	24.960	29.892	8.811	5.497	3.139	3.358
22	5.741	10.496	-----	-----	-----	-----	30.332	28.669	8.487	5.383	3.091	3.001
23	6.103	7.486	-----	-----	-----	-----	40.075	27.913	12.522	5.293	3.051	3.469
24	5.978	7.287	-----	-----	-----	-----	41.804	26.818	17.958	5.241	2.971	4.847
25	5.958	7.121	-----	-----	-----	-----	37.150	25.288	12.644	5.265	3.029	3.133
26	6.706	6.769	-----	-----	-----	-----	31.500	23.841	12.658	5.011	3.041	2.997
27	5.687	6.702	-----	-----	-----	6.702	28.990	22.444	12.169	4.942	3.040*	2.893
28	5.529	6.163	-----	-----	-----	3.534*	28.466	20.690	13.927	4.745	3.208	2.938
29	5.387	6.615	-----	-----		6.697	28.155	19.542	12.335	4.415	3.192	2.845
30	5.867	5.877*	-----	-----		8.198	25.795	26.430	10.962	4.542	3.174	4.463
31	5.309		-----	-----		10.258		20.088		4.499	3.110	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	152.329	190.910	0.000	0.000	0.000	35.389	688.592	922.343	369.408	207.082	108.378	90.687
TOTAL FLOW (cms days)	4.314	5.407	0.000	0.000	0.000	1.002	19.501	26.121	10.462	5.865	3.069	2.568
TOTAL DEPTH (in)	0.870	1.090	0.000	0.000	0.000	0.202	3.931	5.266	2.109	1.182	0.619	0.518
TOTAL DEPTH (cm)	2.209	2.768	0.000	0.000	0.000	0.513	9.986	13.375	5.357	3.003	1.572	1.315

ANNUAL SUMMARY:
Sum of Mean Daily Flow 2765.118 cfs = 78.308 cms
Total Depth 15.787 in = 40.098 cm
Maximum Instantaneous Flow 52.200 cfs = 1.478 cms on April 23 at 17.00 hours

*** Indicates some data were estimated during this day.**
Summaries exclude missing data.

HORSE CREEK STUDY AREA
WATERSHED: 200
WATERSHED AREA: 4169 ACRES (1687 HECTARES)

WATER YEAR 1970
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	5.011	3.533	11.436	-----	9.146	4.485	-----	5.872	38.097	11.636	4.876	3.013
2	6.609	3.253	11.897	-----	3.499	4.391	-----	7.900	38.211	10.876	4.698	3.018
3	4.861	3.232	16.504	-----	3.264	1.043	-----	10.320	37.890	10.180	4.621	3.029
4	3.930	3.189	16.501	-----	3.201	3.715	-----	14.553	37.897	9.683	4.596	3.004
5	3.420	4.008	7.033	-----	3.131	3.686	-----	22.850	36.622	9.444	4.423	2.976
6	3.208	3.845	3.151	-----	3.148	3.813	-----	28.726	34.526	9.021	4.506	6.219
7	3.131	3.684	3.022	-----	3.351	4.411	-----	29.221	32.019	8.641	4.332	3.931
8	4.718	3.317	2.960	-----	3.361	3.898	-----	27.821	29.915	8.292	4.142	3.914
9	4.252	3.183	2.893	-----	3.232	3.723	-----	28.268	29.939	7.761	4.036	3.822*
10	4.062	3.771	2.872	-----	3.207	4.009	-----	27.518	28.300	7.573	3.938	0.013*
11	3.503	3.604	2.851	-----	3.176	-----	-----	25.096	25.281	7.528	3.866	-----
12	3.057	4.349	2.862	-----	3.256	-----	-----	22.502	23.607	7.348	3.776	-----
13	2.881	3.632	2.920	-----	3.738	-----	-----	20.217	22.446	7.919	3.702	-----
14	3.118	3.410	3.090	-----	3.547	-----	-----	18.703	22.489	7.467	3.647	-----
15	3.122	3.588	3.371	-----	3.580	-----	-----	21.889	22.682	6.777	3.587	-----
16	3.055	3.411	3.207	-----	3.853	-----	-----	30.513	20.864	6.500	3.581	1.630*
17	2.968	2.971	3.162	-----	4.347	-----	-----	43.289	19.742	6.404	3.535	3.826
18	2.967	2.810	3.146	-----	3.973	-----	-----	48.254	18.635	6.126	3.459	5.185
19	2.851	2.969	3.312	-----	3.837	-----	-----	52.768	17.706	5.864	3.385	4.382
20	2.914	3.048	4.312	-----	3.781	-----	-----	53.017	16.888	5.642	3.379	4.811
21	2.920	2.997	4.516	-----	3.754	-----	-----	49.746	16.078	6.059	3.341	5.126
22	2.934	3.018	7.774	-----	3.673	-----	-----	47.609	15.244	5.673	3.243	7.960
23	2.934	2.966	4.561	-----	3.645	-----	-----	47.293	14.509	5.575	3.212	5.259
24	3.487	2.903	3.938	-----	3.749	-----	-----	46.655	13.735	5.441	3.137	4.530
25	3.105	2.810	3.397	-----	3.981	-----	-----	48.069	12.520	5.332	3.045	4.194
26	2.910	2.800	4.437	-----	3.979	-----	-----	49.809	11.742	5.343	2.997	3.996
27	3.271	2.744	3.507	-----	3.951	2.592	-----	45.023	12.629	5.366	2.966	3.730
28	3.474	4.014	3.357	-----	3.934	4.617	-----	40.670	13.825	6.337	2.959	3.626
29	3.396	7.871	2.210	-----		4.580	-----	41.729	13.604	6.025	2.953	3.423
30	3.473	11.500	9.330	-----		4.449	-----	41.355	13.465	5.271	2.950	3.261
31	3.623		16.291	-----		4.607		38.771		5.088	2.974	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	109.166	112.428	173.817	0.000	106.295	58.016	0.000	1036.023	691.106	222.189	113.859	97.878
TOTAL FLOW (cms days)	3.092	3.184	4.923	0.000	3.010	1.643	0.000	29.340	19.572	6.292	3.224	2.772
TOTAL DEPTH (in)	0.623	0.642	0.992	0.000	0.607	0.331	0.000	5.915	3.946	1.269	0.650	0.559
TOTAL DEPTH (cm)	1.583	1.630	2.521	0.000	1.541	0.841	0.000	15.024	10.022	3.222	1.651	1.419

ANNUAL SUMMARY:
Sum of Mean Daily Flow 2720.777 cfs = 77.052 cms
Total Depth 15.533 in = 39.455 cm
Maximum Instantaneous Flow 61.120 cfs = 1.731 cms on May 19 at 17.30 hours

* Indicates some data were estimated during this day.
Summaries exclude missing data.

HORSE CREEK STUDY AREA
WATERSHED: 200
WATERSHED AREA: 4169 ACRES (1687 HECTARES)

WATER YEAR 1971
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	3.203	3.746	4.087	6.680	7.219	5.541	5.458*	28.419	40.222*	13.273	5.149	4.919
2	3.142	3.466	4.485	6.495	6.715	6.218	5.432*	37.916	39.028*	12.829	5.211	6.372
3	3.092	3.343	6.450	5.541	6.482	5.223	5.382*	52.375	37.295*	12.090	5.193	5.866
4	3.017	3.348	6.086	14.065	6.349	4.915	5.419*	64.188	38.191*	11.510	5.067	4.677
5	4.720	4.184	6.722	11.467	6.020	4.877	5.721*	61.356	35.835*	11.024	5.593	4.301
6	3.661	4.409	4.740	11.271	5.803	5.606	6.850*	54.325	34.018	11.446	5.412	4.091
7	3.489	4.867	4.993	11.255	5.546	4.765	8.129*	53.400	33.106	10.478	5.167	3.998
8	3.650	4.479	5.180	11.261	5.557	4.732	8.809*	57.422	33.878	9.964*	4.865	3.851
9	10.417	4.658	4.930	11.265	5.343	4.682	9.244*	58.964	30.430	9.654*	4.655	3.706
10	5.894	4.518	4.204	11.261	9.339	4.662	10.238*	59.344	29.719	10.267*	4.511	3.620
11	4.868	4.663	3.898	11.262	9.236	4.621	10.741*	61.538	29.132	9.361*	4.452	3.529
12	5.235	6.290	3.821	11.284	8.084	4.628	10.696*	64.499	26.932	8.941*	4.369	3.483
13	4.354	5.395	9.619	11.239	8.476	4.613	10.661	66.117	26.482	8.587*	4.321	3.420
14	4.071	4.660	14.693	11.192	8.756	4.477	11.740	58.823*	24.881	7.848	4.309	3.371
15	3.883	4.706	9.129	11.192	9.175	4.431	13.548	56.241*	22.905	7.246	4.292	3.353
16	3.734	5.641	5.048	11.192	9.200	4.371	13.452	53.297*	21.643	7.150	4.238	3.291
17	3.615	5.711	4.505	11.192	9.111	4.323	13.650	44.958*	20.479	6.909	4.140	3.275
18	3.596	5.241	4.561	11.192	8.856	4.323	12.920	39.989*	20.328	6.768	4.054	3.275
19	3.828	4.996	4.656	10.062	8.590	4.857	12.819	38.541*	20.384	6.637	3.992	3.264
20	3.700	4.880	5.274	7.057	8.117	4.323	13.188	35.632*	18.344	6.636	3.857	3.221
21	3.909	3.559	5.872	5.150	7.747	4.236	14.540	33.366*	17.283	6.526	3.800	3.214
22	4.206	6.302	5.342	5.071	7.584	4.237	16.256	34.012*	16.434	6.305	4.209	3.182
23	4.077	8.378	8.266	5.057	7.334	5.170	18.570	35.354*	15.554	6.143	4.396	3.110
24	4.714	6.916	7.760	4.934	7.069	5.500	18.662	36.918*	14.843	6.061	4.004	3.069
25	3.996	5.577	7.102	4.848	6.607	4.973	18.725	39.313*	19.816	5.972	3.826	3.173
26	3.771	5.004	5.457	5.063	6.282	5.065	18.511	41.914*	15.586	5.854	3.750	3.393
27	3.318	4.705	7.335	5.058	6.145	5.236	17.972	44.302*	14.520	5.744	3.676	4.509
28	4.148	4.726	6.349	4.988	5.892	5.135	18.567	45.953*	19.572	5.635	3.605	3.831
29	3.899	4.782	7.203	4.909		5.139*	20.438	45.149*	15.191	5.515	3.552	3.751
30	3.878	4.881	6.436	7.163		5.340*	23.030	42.467*	13.962	5.347	3.497	3.497
31	3.830		6.468	8.049		5.459*		39.928*		5.226	4.192	

MONTHLY SUMMARY:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	128.916	148.031	190.670	267.714	206.632	151.679	379.369	1486.020	745.991	252.944	135.354	113.613
TOTAL FLOW (cms days)	3.651	4.192	5.400	7.582	5.852	4.296	10.744	42.084	21.126	7.163	3.833	3.218
TOTAL DEPTH (in)	0.736	0.845	1.089	1.528	1.180	0.866	2.166	8.484	4.259	1.444	0.773	0.649
TOTAL DEPTH (cm)	1.869	2.147	2.765	3.882	2.996	2.200	5.501	21.549	10.818	3.668	1.963	1.648

ANNUAL SUMMARY:

Sum of Mean Daily Flow 4206.933 cfs = 119.140 cms
Total Depth 24.018 in = 61.006 cm
Maximum Instantaneous Flow 71.400 cfs = 2.022 cms on May 12 at 17.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 200
WATERSHED AREA: 4169 ACRES (1687 HECTARES)

WATER YEAR 1972
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	3.391	3.269	10.198	10.363*	2.272	3.408	8.508	15.324	101.034	20.695	7.769	4.281
2	3.262	3.195	24.863	10.548*	2.237	3.327	10.845	15.200	90.566	20.139	7.532	4.293
3	3.191	3.315	13.522	10.525*	2.302	3.116	10.121	17.566	84.823	20.022	7.384	4.253
4	3.149	3.492	7.730	10.521*	2.275	3.211	10.149	21.685	78.912	19.570	7.284	4.178
5	3.059	3.234	5.672	9.144*	2.213	3.893	10.654	27.276	76.489	19.448	7.138	4.309
6	3.030	4.907	5.709	3.566*	2.207	4.558	13.030	34.070	68.322	19.666	6.973	4.373*
7	2.985	3.191	5.069*	3.527*	2.256	3.836	14.687	39.163	61.834	19.411	6.803	4.159*
8	2.969	2.994	5.064*	4.947*	2.289	3.447	14.837	47.087*	62.255	18.408	6.513	4.140*
9	2.963	3.232	6.756*	5.948*	2.196	3.346	14.114	50.135*	56.060	18.422	5.427	4.140*
10	2.906	3.654	7.653*	6.173*	2.236	4.154	13.372	47.007	54.054	17.117	5.355	4.137*
11	2.822	3.943	8.302*	6.106*	2.206	5.643	12.805	42.922	45.532	14.799	5.277	4.779*
12	2.826	4.883	8.710*	6.135*	2.068	6.559	12.262	46.305	38.735	11.688	5.224	7.065*
13	5.095	4.374	9.146*	6.182*	2.072	8.180	11.436	56.288	35.533	11.340	5.217	4.213*
14	4.094	3.820	9.033*	11.098*	2.227	8.828	10.589	70.108	34.327	10.977	5.314	4.700*
15	3.292	3.499	9.185*	7.664	2.145	9.330	10.179	79.871*	33.126	10.712	6.554	4.794*
16	3.199	3.346	9.347*	4.417	2.223	10.966	10.211	96.377*	32.936	10.397	6.605	4.638*
17	3.188	3.241	9.282*	2.246	2.161	14.719	9.575	97.946*	30.649	10.206	5.504	4.726*
18	3.102	3.151	11.309*	2.130	2.144	16.995	9.144	93.344*	30.380	10.390	5.368	4.604*
19	4.136	3.195	11.991*	2.080	2.211	16.756	8.875	78.567*	28.567	11.320	5.303	5.816*
20	4.344	3.580	10.456*	2.793	2.243	15.975	8.777	81.790	28.262	11.180	5.123	4.991*
21	3.788	3.452	8.067*	2.974	2.168	14.588	8.683	86.293	28.852	12.514	4.997	4.922*
22	3.514	3.411	5.807*	2.428	2.180	14.199	8.585	79.819	26.274	10.776	4.981	4.794*
23	3.645	2.860	5.058*	2.219	2.221	18.502	8.585	77.990	26.430	9.785	5.308	4.280*
24	3.590	3.312	4.717*	2.118	2.200	17.371	9.088	74.663	24.867	9.414	5.023	4.707*
25	3.298	3.226	4.498*	2.074	2.193	15.552	9.300	67.390	24.599	9.124	4.845	4.492*
26	4.513	3.138	4.869*	2.042	2.194	13.529	9.253	65.100	24.165	8.836	4.675	4.325*
27	3.323	3.212	4.196*	2.118	2.212	12.110	10.614	71.236	23.575	8.607	4.534	5.123*
28	11.870	3.453	3.931*	2.170	2.172	10.809	14.281	82.721	22.544	8.329	4.440	4.167*
29	18.090	3.293	3.916*	2.207	2.299	9.724	16.422	94.091	21.697	8.135	4.384	4.919*
30	8.692	3.193	3.692*	2.211		8.939	15.685	97.469	21.220	7.938	4.551	4.574*
31	3.828		6.995*	2.246		8.485		101.846		7.921	4.289	

MONTHLY SUMMARY:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	135.153	104.064	244.741	150.919	64.021	294.053	334.667	1956.650	1316.617	407.285	175.692	138.889
TOTAL FLOW (cms days)	3.828	2.947	6.931	4.274	1.813	8.328	9.478	55.412	37.287	11.534	4.976	3.933
TOTAL DEPTH (in)	0.772	0.594	1.397	0.862	0.366	1.679	1.911	11.171	7.517	2.325	1.003	0.793
TOTAL DEPTH (cm)	1.960	1.509	3.549	2.189	0.928	4.264	4.853	28.374	19.093	5.906	2.548	2.014

ANNUAL SUMMARY:
Sum of Mean Daily Flow 5322.751 cfs = 150.740 cms
Total Depth 30.389 in = 77.187 cm
Maximum Instantaneous Flow 115.400 cfs = 3.268 cms on May 31 at 13.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 200
WATERSHED AREA: 4169 ACRES (1687 HECTARES)

WATER YEAR 1973
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	3.611	4.206	5.276	16.456*	7.906	7.911	3.147	10.690*	7.038	5.030*	2.370	2.583*
2	3.410	5.527	3.875	16.482*	7.911	7.927	3.067	10.403*	7.367	5.017*	2.327	2.558*
3	3.519	4.703	4.273	16.568*	7.917	7.911	3.107	12.843*	6.799	4.858*	2.290	2.561*
4	3.922	6.297	14.773	16.337*	7.911	7.911	6.101	14.865	6.411	4.686*	2.295	2.489*
5	4.061	6.182	16.712*	16.417*	7.911	8.182	10.411	14.682	6.146	4.671*	2.283	2.411*
6	3.916	4.645	16.448*	16.390*	7.911	8.409	10.767	14.766	5.852	4.651*	2.248	2.312*
7	3.854	4.366	16.395*	16.515*	7.915	8.492	10.528	14.380	5.726	4.575*	2.239	2.625
8	3.821	4.485	16.382*	16.538*	7.911	8.495	11.025	15.103	5.434	4.494*	2.220	2.719
9	4.163	4.217	16.443*	16.462*	7.911	8.495	11.249	13.694	5.672	4.356*	2.188	2.535
10	5.393	4.229	16.505*	16.377*	7.934	8.495	12.407	12.870	5.314	4.248*	2.278	2.441
11	4.379	4.120	16.634*	16.318*	7.941	8.521	9.542	12.246	5.091	4.085*	2.317	2.379
12	4.068	4.090	16.877*	16.240*	7.972	8.529	8.386	12.738	5.065	4.016*	2.348	2.373
13	3.949	4.006	16.760*	16.317*	7.945	8.495	10.121	13.393	5.109	3.964*	2.373	2.353
14	3.890	4.007	16.769*	16.515*	7.941	8.550	9.731	13.989	14.437	3.865*	2.389	2.813
15	3.862	4.062	16.719*	16.660*	7.941	8.526	9.232	14.395	9.903	3.744*	2.418	2.622
16	3.859	4.015	16.537*	16.732*	7.941	8.534	9.598	14.268	8.025	3.644*	2.428	2.451
17	3.838	3.909	16.473*	16.695*	7.941	8.557	10.085	13.876	11.306	3.450	2.402	2.412
18	3.766	3.934	16.528*	16.756*	7.941	8.561	8.648	13.059	10.004	3.384	2.336	2.397
19	3.788	3.556	16.542*	16.810*	7.941	8.589	8.149	12.242*	8.494	3.349	2.270	3.784
20	3.762	3.706	16.572*	16.836*	7.941	8.589	7.542	11.163*	7.727	3.876	2.235	5.619
21	3.707	6.607	16.716*	16.951*	7.941	8.589	7.494	10.213*	7.196	8.055	2.224	4.016
22	3.673	19.854	16.848*	17.208*	7.926	8.589	8.047	10.128*	6.806	2.685	2.480	3.176
23	4.111	30.684	16.850*	16.298*	7.913	8.589	8.767	9.740	6.510	2.275	2.597	3.136
24	3.861	22.787	16.736*	14.692*	7.911	8.620	8.932	10.362	6.379	2.261	2.470	3.888
25	3.747	16.235	16.838*	13.650*	7.911	8.620	9.544	11.240	6.381	2.348	2.503	6.643
26	4.334	27.938	16.783*	12.781*	7.911	8.647	11.095	9.334	6.322	2.398	2.524	4.202
27	3.998	10.235	16.773*	11.917*	7.911	8.705	13.457	8.505	6.067	2.434	2.515	4.703
28	3.901	7.307	16.783*	10.955*	7.911	8.755	12.171	8.038	6.086	2.522	2.461	6.244
29	3.821	5.473	16.696*	9.443*		8.809	11.296	7.607	5.683	2.555	2.430	3.002
30	3.687	5.241	16.699*	8.113*		6.034	10.688	7.277	5.257	2.538	2.443	2.735
31	3.263		16.522*	7.880		3.279		7.650		2.468	2.723	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	120.937	240.622	477.734	470.310	221.914	254.912	274.336	365.759	209.607	116.498	73.624	96.181
TOTAL FLOW (cms days)	3.425	6.814	13.529	13.319	6.285	7.219	7.769	10.358	5.936	3.299	2.085	2.724
TOTAL DEPTH (in)	0.690	1.374	2.727	2.685	1.267	1.455	1.566	2.088	1.197	0.665	0.420	0.549
TOTAL DEPTH (cm)	1.754	3.489	6.928	6.820	3.218	3.697	3.978	5.304	3.040	1.689	1.068	1.395

ANNUAL SUMMARY:
Sum of Mean Daily Flow 2922.432 cfs = 82.763 cms
Total Depth 16.685 in = 42.379 cm
Maximum Instantaneous Flow 43.930 cfs = 1.244 cms on November 26 at 3.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 200
WATERSHED AREA: 4169 ACRES (1687 HECTARES)

WATER YEAR 1974
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	2.721*	3.700*	4.053	15.577	4.966	3.017*	8.036*	31.593	40.762	11.540	3.723	4.003
2	2.653*	2.704*	3.896	15.704	4.961	3.154*	7.989*	31.588	44.946	10.936	3.698	3.904
3	2.653*	2.987*	3.454	11.357	5.089	2.841*	7.780*	30.626	49.029	10.336	3.917	3.837
4	2.735*	3.050*	3.289	1.052	5.080	2.796*	7.293*	31.054	56.639	9.884	3.734	3.742
5	2.794*	3.503*	8.948	0.936	5.159	2.762*	6.632*	34.796	64.030	9.969	3.632	3.715
6	2.810*	3.724*	16.608	0.936	5.191	2.734*	6.318	40.293	58.031	9.677	3.766	3.735
7	3.241*	3.940*	12.242	0.936	5.241	2.686*	6.112	46.595	58.786	9.288	3.531	3.639
8	3.021*	3.531*	4.190	0.936	5.467	2.670*	6.228	50.966	57.974	8.834	3.930	3.550
9	3.076*	5.663*	8.398	0.950	5.740	4.741*	6.858	46.905	51.883	8.548	4.524	3.733
10	3.100*	8.131*	11.539	0.949	5.937	2.578*	7.136	43.399	46.813	9.792	5.054	5.276
11	2.871*	8.411*	17.883	0.950	5.925	2.755*	7.652	33.541	46.683	10.267	5.173	4.621
12	2.408*	9.890*	24.171	0.950	5.929	2.816*	8.245	30.710	47.247	8.252	5.173	4.123
13	2.550	8.211*	24.186	0.952	5.934	2.881*	8.073	28.330	47.342	7.335	5.057	3.875
14	3.051	6.295*	24.507	0.958	5.885	2.811*	8.356	26.347	50.431	7.087	5.202	3.763
15	2.638	5.791*	24.432	0.967	5.864	2.722*	9.203	23.900	46.529	6.812	5.003	3.628
16	2.597	5.453*	22.830	0.955	5.908	3.053*	10.219	20.973	40.526	6.218	4.856	3.527
17	2.569	4.399*	18.443	0.952	5.911	7.649*	10.993	18.783	37.554	5.871	4.743	3.417
18	2.524	3.682*	21.294	0.960	5.901	4.048*	13.422	17.365	31.862	5.249	4.657	3.324
19	2.498	2.902	22.660	0.965	5.932	4.375*	15.449	17.041	26.021	6.341	4.592	3.274
20	2.479	6.107	22.595	0.973	5.919	4.165*	15.069	19.923	26.896	5.704	4.359	3.204
21	2.477	8.318	22.343	0.964	5.976	3.919*	14.194	22.898	23.596	4.419	4.360	3.135
22	2.494	6.036	21.955	0.972	5.952	3.790*	14.771	24.252	17.737*	4.326	5.172	3.069
23	2.523*	4.994	22.358	0.957	5.954	3.830*	18.555	26.734	15.297*	4.417	5.004	3.001
24	3.177*	4.936	22.867	0.964	6.435	3.695*	27.142	29.966	15.431*	4.237	4.838	2.949
25	3.883*	5.815	24.575	0.969	5.747	3.534*	35.629	36.340	15.212*	4.146	4.652	2.927
26	2.969*	8.230	23.195	0.962	5.503*	4.009*	39.266	49.573	15.374*	4.052	4.495	2.906
27	2.847*	6.094	13.926	0.960	3.962*	5.027*	32.211	54.014	14.692	3.883	4.379	2.988
28	3.066*	4.902	9.953	1.226*	2.852*	5.847*	27.244	51.150	14.007	3.812	4.288	2.907
29	3.743*	4.716	6.982	1.791*		6.156*	25.983	48.019	13.054	3.886	4.174	2.841
30	3.433*	3.900	11.043	1.810*		7.382*	26.429	44.317	12.244	3.879	4.091	2.831
31	3.760*		13.215	3.146		7.895*		42.031		3.792	4.018	

MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	89.359	160.014	492.027	73.638	154.320	122.335	438.486	1054.020	1086.628	212.788	137.792	105.442
TOTAL FLOW (cms days)	2.531	4.532	13.934	2.085	4.370	3.465	12.418	29.850	30.773	6.026	3.902	2.986
TOTAL DEPTH (in)	0.510	0.914	2.809	0.420	0.881	0.698	2.503	6.018	6.204	1.215	0.787	0.602
TOTAL DEPTH (cm)	1.296	2.320	7.135	1.068	2.238	1.774	6.359	15.285	15.758	3.086	1.998	1.529

ANNUAL SUMMARY:
Sum of Mean Daily Flow 4126.849 cfs = 116.872 cms
Total Depth 23.561 in = 59.845 cm
Maximum Instantaneous Flow 76.480 cfs = 2.166 cms on June 5 at 16.30 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 200
WATERSHED AREA: 4169 ACRES (1687 HECTARES)

WATER YEAR 1975
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.923	1.116	2.907*	2.881*	2.440*	4.086*	1.990	3.097	53.201*	19.430*	3.683*	4.674*
2	0.923	1.015	3.018*	2.612	2.440*	5.137*	1.960	3.563	59.490*	18.379*	3.432*	4.886*
3	0.923	0.968	3.082*	2.265	2.411*	4.798*	2.000	3.735	62.031*	17.608*	3.219*	4.515*
4	0.923	0.947	3.124*	1.969	2.421*	4.248*	2.043	3.401	52.624*	16.758*	3.062*	4.270*
5	0.923	1.032	3.039*	1.920	2.450*	3.742*	2.221	3.576	50.813*	15.749*	2.918*	4.290*
6	0.942	1.045	2.964	1.986*	2.421*	3.242*	2.532	3.754	57.116*	14.707*	2.801*	4.461*
7	0.964	1.164	2.999	2.058*	2.411*	2.862*	2.751	3.850	56.853*	13.934*	3.739*	4.381*
8	0.952	1.247	3.018*	2.055*	2.411*	2.810*	2.810	4.488	48.292*	13.020*	2.988*	4.217*
9	0.943	1.048	3.018*	2.069*	2.411*	2.810*	2.841	6.888	43.753*	12.328*	2.764*	4.052*
10	0.928	1.048	3.018	2.044*	2.411*	2.831*	2.986	12.610	38.668*	11.441*	2.626*	3.870*
11	1.101	1.103	2.976	2.056*	2.411*	2.831*	3.317	18.221	38.940*	10.733*	2.539*	3.736*
12	0.955	1.129	2.971	2.049*	2.411*	2.851*	3.283	22.652	41.541*	10.606*	2.470*	3.619*
13	0.935	1.504	2.997	2.371*	2.581*	2.882*	3.441	23.951	38.564*	12.191*	2.403*	3.512*
14	0.923	1.129	3.018	3.434*	2.852*	2.945*	3.410	31.928	36.223*	11.183*	2.334*	3.359*
15	0.923	1.063	2.955	2.863*	2.614*	3.029*	3.499	46.202	34.102*	10.611*	2.258*	3.282*
16	0.909	1.002	3.226	2.342*	2.510*	3.114*	3.242	46.341	25.973*	9.799*	2.288*	3.562
17	0.903	1.246	3.105	2.805*	2.426*	3.229*	2.898	37.828	23.960*	8.748*	2.843*	5.137
18	0.896	1.272	3.016	19.626*	2.411*	3.449*	3.290	33.994	23.830*	8.361*	3.777*	4.048
19	0.895	1.115	2.981	12.367*	2.411*	3.498	3.365	28.565	24.061*	7.859*	3.786*	4.476
20	0.884	1.154	3.349	7.679*	2.411*	3.451	3.027	19.834	26.704*	7.158*	3.883*	4.546
21	1.253	1.305	3.686	6.264*	2.411*	3.418	3.147	17.150	25.352*	6.278*	2.934*	4.615
22	1.107	1.360	3.018*	5.289*	2.411*	3.373	3.355	15.198	24.939*	5.387*	3.231*	4.574
23	1.018	1.215	2.960*	5.104*	2.627*	3.336	3.782	18.177	24.507*	4.842*	7.072*	4.568
24	0.979	1.193	2.852	4.714*	2.945	3.319	3.694*	18.155	25.147*	4.383*	7.626*	4.532
25	0.981	1.202	2.810	3.114*	2.862*	3.286	3.728	21.749	24.316*	4.051*	3.977*	4.482
26	0.969	0.996	2.764	3.050*	2.779*	3.226	3.405	20.835	23.778*	3.936*	3.436*	4.372
27	0.952	1.123	2.728	2.994*	2.734*	2.710	3.226	21.298	23.379*	3.825*	3.329*	4.333
28	1.017	2.992*	2.775*	2.876*	3.802*	2.412	2.967	23.764*	20.018*	3.712*	4.305*	4.256
29	0.962	2.810*	2.992*	2.618*		2.372	2.939	29.847*	19.779*	4.277*	4.500*	4.189
30	0.939	2.841*	3.029*	2.465*		2.076	2.974	37.928*	19.635*	3.918*	4.236*	4.156
31	0.950		3.002*	2.421*		2.017		46.682*		3.915*	4.588*	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	29.794	39.381	93.399	120.356	71.835	99.388	90.123	629.259	1067.585	299.122	109.042	126.966
TOTAL FLOW (cms days)	0.844	1.115	2.645	3.408	2.034	2.815	2.552	17.821	30.234	8.471	3.088	3.596
TOTAL DEPTH (in)	0.170	0.225	0.533	0.687	0.410	0.567	0.515	3.593	6.095	1.708	0.623	0.725
TOTAL DEPTH (cm)	0.432	0.571	1.354	1.745	1.042	1.441	1.307	9.125	15.481	4.338	1.581	1.841

ANNUAL SUMMARY:
Sum of Mean Daily Flow 2776.251 cfs = 78.623 cms
Total Depth 15.850 in = 40.259 cm
Maximum Instantaneous Flow 72.940 cfs = 2.066 cms on June 2 at 19.30 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 200
WATERSHED AREA: 4169 ACRES (1687 HECTARES)

WATER YEAR 1976
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	4.126	4.503	37.332	10.909*	6.485*	5.130	5.665	27.725	37.275	19.255	5.907	5.646
2	4.056	4.548	69.836	13.167*	6.034*	5.130*	5.441	34.477	35.100	18.463	7.127	5.476
3	3.973	6.386	25.391	13.338*	6.034*	5.130*	5.721	42.577	32.349	17.780	6.667	5.330
4	4.474	6.538	11.288	11.637*	6.196*	5.086*	7.164	59.234	31.205	17.211	7.372	5.226
5	4.300	7.194	8.648	7.227*	6.782*	5.079*	9.836	57.203	31.224	16.571	6.420	5.163
6	4.043	7.357	7.742	5.684*	6.992*	5.079*	10.965	53.967	31.318	16.000	6.946	8.371
7	5.181	6.790	10.744	4.295*	7.108*	5.079*	9.824	56.985	31.115	15.462	11.766	6.023
8	4.335	5.775	13.746	4.009*	7.055*	5.079*	14.806	66.300	31.024	14.971	11.670	5.548
9	4.780	5.388	14.100	4.191*	7.123*	5.079*	19.881	73.021	30.353	14.472	8.897	5.319
10	4.540	5.791	14.110	4.283*	7.108*	5.104*	22.247	82.034	30.470	13.826	8.006	5.185
11	4.446	6.952	12.973	4.297*	7.108*	5.055	25.987	100.100	28.514	13.401	7.409	5.537
12	4.679	4.597	11.999	4.187*	7.152*	4.977	29.286	101.484	28.427	18.827	7.223	5.940
13	3.857	7.765	10.432	4.204*	7.197*	4.977	29.888	92.368	27.723	11.995	7.105	5.210
14	3.876	5.867	8.891	4.161*	7.166*	4.977	29.493	88.075	26.570	9.082	6.914	5.047
15	3.826	5.125	8.246	7.961*	7.166*	4.951	26.809	81.331	25.160	8.211	9.212	4.916
16	3.602	5.036	7.283	8.531*	7.166*	4.942	23.548	75.546	30.803	8.075	8.290	5.146
17	3.645	4.791	6.410	7.900*	7.166*	4.977*	20.757	71.148	30.028	9.025	7.079	5.473
18	3.848	6.602	11.866	8.027*	7.166*	5.002*	18.712	63.549	28.229	9.110	7.363	5.275
19	3.575	17.525	12.429*	7.941*	7.166*	5.008*	16.965	61.951	27.613	7.934	6.970	4.966
20	4.472	26.963	9.762*	7.931*	7.166*	5.028*	16.931	58.353	28.513	7.524	6.765	4.837
21	10.560	27.748	9.030*	7.777*	7.004*	5.076	15.467	55.238	29.179	7.968	6.615	4.813
22	7.178	29.601	8.683*	7.569*	6.760*	5.209	15.293	53.961	28.364	7.062	6.770	4.838
23	5.052	24.763	8.472*	7.350*	6.622*	5.205	15.428	53.566	26.154	6.786	7.447	5.470
24	4.436	21.147	8.710*	7.231*	6.420*	5.130	17.344	53.991	24.920	8.398	6.591	5.025
25	4.777	7.473	8.228*	7.033*	6.199*	5.130	17.449	54.945	24.113	6.940	8.612	4.888
26	4.764	5.105	9.370*	6.886*	5.964*	5.130	16.410	54.945	22.816	6.474	8.148	4.825
27	4.031	5.353	8.285*	6.856*	5.675*	5.130	15.825	48.507	21.765	6.139	6.740	4.811
28	3.856	5.194	7.929*	6.753*	5.219	5.130	15.773	46.873	21.070	6.050	6.428	4.753
29	3.946	4.275	8.314*	6.584*	5.130	5.098	18.094	43.150	20.493	6.053	6.133	4.719
30	4.881	3.238	8.084*	6.360*		5.330	21.869	40.495	19.801	5.985	5.954	4.677
31	5.459		6.364*	6.203*		5.711		40.238		5.985	5.802	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	142.574	285.388	404.698	220.481	193.530	158.148	518.878	1893.336	841.686	341.035	230.348	158.451
TOTAL FLOW (cms days)	4.038	8.082	11.461	6.244	5.481	4.479	14.695	53.619	23.837	9.658	6.523	4.487
TOTAL DEPTH (in)	0.814	1.629	2.310	1.259	1.105	0.903	2.962	10.809	4.805	1.947	1.315	0.905
TOTAL DEPTH (cm)	2.068	4.139	5.869	3.197	2.806	2.293	7.524	27.456	12.206	4.945	3.340	2.298

ANNUAL SUMMARY:
Sum of Mean Daily Flow 5388.553 cfs = 152.604 cms
Total Depth 30.764 in = 78.141 cm
Maximum Instantaneous Flow 113.570 cfs = 3.216 cms on May 13 at 4.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 200
WATERSHED AREA: 4169 ACRES (1687 HECTARES)

WATER YEAR 1977
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	4.635	6.898	4.771	4.459	4.404	4.404	4.356	25.443	9.109	3.671	2.576	3.251
2	6.215	5.355	5.472	4.569	4.404	4.404	4.402	24.592	8.659	4.338	2.508	3.192
3	6.270	5.098	6.884	4.453	4.404	4.366	4.356	21.868	8.037	3.893	2.436	3.075
4	5.123	4.949	8.166	4.453	4.404	4.356	4.600	17.710	7.652	4.129	2.404	2.994
5	4.913	4.862	8.419	4.453	4.404	4.350	4.356	14.536	7.285	3.900	2.371	2.860
6	4.746	4.749	10.193	4.453	4.404	4.356	4.356	13.467	6.995	3.898	2.345	2.796
7	4.626	4.644	10.904	4.453	4.404	4.376	4.283	14.618	6.827	3.621	2.304	2.724
8	4.597	4.559	7.662	4.453	4.404	4.357	4.306	15.397	8.852	3.541	2.224	2.655
9	4.536	4.519	5.115	4.452	4.405	4.356	4.332	15.039	6.722	3.514	2.212	2.587
10	4.671	4.454	4.828	4.453	4.404	4.356	4.332	15.842	6.314	3.508	2.206	2.535
11	6.712	4.394	4.794	4.453	4.404	4.356	4.332	13.987	6.627	3.468	2.151	2.501
12	4.961	4.268	4.715	4.344	4.404	4.356	4.332	13.092	6.541	3.395	2.112	2.450
13	4.786	4.238*	4.611	4.356	4.854*	4.356	4.307	13.124	6.760	3.316	2.097	2.428
14	4.646	4.417*	4.504	4.380	4.404	4.332	4.307	11.932	6.351	3.243	2.090	2.411
15	4.528	4.641*	4.422	4.380	4.404	4.356	4.307	11.506	5.851	3.146	2.133	3.066
16	4.423	5.016*	4.400	4.380	4.405	4.356	4.229	11.452	5.518	3.037	2.144	4.266
17	4.362	5.229	4.367	4.794*	4.404	4.356	4.211	12.035	5.182	2.973	2.324	4.201
18	4.293	6.068	4.318	6.906*	4.405	4.336	4.200	11.972	4.967	3.839	2.127	3.252
19	4.221	4.954	4.299	6.208*	4.404	4.332	4.187	12.978	4.865	3.720	2.142	3.113
20	4.228	4.753	4.282	4.416*	4.404	4.332	4.164	12.664	5.050	3.460	2.154	4.832
21	4.185	4.609*	4.283	4.404	4.404	4.356	4.164	12.460	4.791	3.262	2.146	4.665
22	4.170	4.633*	4.314	4.314	4.450*	4.356	4.140	12.225	4.565	3.295	2.178	3.864
23	4.168	4.809*	4.305	4.404	5.097*	4.332	13.949	12.532	4.379	3.161	2.225	3.172
24	4.118	5.002	4.371	4.404	4.315	4.356	21.772	12.246	4.190	3.707	2.720	3.254
25	5.101	5.130	4.397	4.404	4.404	4.332	25.753	11.373	4.072	4.168	3.615	3.504
26	5.210	4.723*	4.555	4.404	4.404	4.356	24.685	10.958	3.944	3.846	5.664	3.467
27	4.916	4.688*	4.590	4.404	4.314	4.361	22.568	10.527	3.836	3.423	5.073	3.232
28	4.717	4.837*	4.498	4.404	4.404	4.332	22.419	9.754	3.748	3.127	3.431	3.743
29	4.523	4.898*	4.478	4.404		4.356	21.834	9.549	3.665	3.015	3.659	4.359
30	4.447	4.807	4.409	4.404		4.332	22.867	9.181	3.623	2.814	7.029	4.536
31	4.404		4.463	4.404		4.332		9.206		2.681	4.100	

MONTHLY SUMMARY:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	147.451	146.199	165.791	141.622	124.329	134.940	270.404	423.265	174.977	108.111	86.898	98.984
TOTAL FLOW (cms days)	4.176	4.140	4.695	4.011	3.521	3.822	7.658	11.987	4.955	3.062	2.461	2.803
TOTAL DEPTH (in)	0.842	0.835	0.947	0.809	0.710	0.770	1.544	2.417	0.999	0.617	0.496	0.565
TOTAL DEPTH (cm)	2.138	2.120	2.404	2.054	1.803	1.957	3.921	6.138	2.537	1.568	1.260	1.435

ANNUAL SUMMARY:

Sum of Mean Daily Flow 2022.971 cfs = 57.291 cms
Total Depth 11.550 in = 29.336 cm
Maximum Instantaneous Flow 37.020 cfs = 1.048 cms on May 1 at 22.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 200
WATERSHED AREA: 4169 ACRES (1687 HECTARES)

WATER YEAR 1978
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	4.019	3.213	5.312	6.096*	4.666	5.275	46.487	40.608	27.954	10.129	5.717	4.696
2	3.535	4.537	31.752	5.466*	4.692	6.145	40.779	38.772	27.342	10.524	5.593	4.582
3	3.360	3.303	19.861	5.305*	4.716	7.435	35.895	36.974	27.217	10.522	5.622	4.427
4	3.078	3.148	14.674	5.076*	4.707	5.634	31.426	33.371	26.985	17.753	5.734	4.374
5	2.810	3.366	11.800	4.836*	4.746	5.685	26.746	29.851	26.807	12.576	5.574	4.724
6	2.865	3.382	10.708	4.652*	5.359	5.602	24.112	28.189	25.513	11.114	5.439	5.050
7	4.334	3.155	10.163*	4.492*	5.085	5.427	22.467	27.279	24.260	14.986	5.367	6.130
8	3.776	3.020*	9.296*	4.572*	4.906	5.623	21.046	28.404	22.991	12.913	5.402	5.481
9	4.625	3.060*	8.408*	4.734	4.825	6.522	20.944	28.788	21.944	11.781	5.155	4.834
10	3.794	3.060*	7.602	4.541	4.803	6.086	20.813	36.533	23.565	11.439	5.240	4.646
11	3.390	3.060	7.538	4.878	4.805	6.027	22.622	39.421	20.492	10.609	5.171	5.788
12	3.364	3.060	7.293	5.156	4.283	6.055	21.838	36.214	18.895	9.887	5.263	7.561
13	3.436	3.165	7.915	5.130	13.596	6.061	21.505	37.696	18.675	9.426	7.757	5.625
14	3.121	3.384	11.499	5.130	8.721	6.117	21.024	38.877	17.573	9.108	6.288	5.376
15	3.018	4.179	12.170	5.120	4.725	6.066	21.168	39.655	16.838	9.195	6.722	5.094
16	2.935	3.547	11.662	5.002	4.687	6.015	21.588	36.649	15.774	9.050	7.514	4.951
17	2.837	2.705	11.359	4.993	4.732	6.199	20.036	34.422	15.162	8.788	7.246	4.886
18	2.805	2.374*	10.775	5.002	4.663	6.673	19.678	32.960	15.263	8.364	6.101	5.114
19	2.751	2.392*	9.915*	4.977	4.624	7.425	20.512	33.673	14.230	7.906	5.826	5.027
20	2.698	2.392*	9.423*	4.930	4.851	8.412	21.429	33.653	13.287	7.590	5.587	4.681
21	2.670	2.382*	9.245*	4.882	4.839	9.767	20.292	34.462	12.743	7.299	5.443	4.514
22	2.631	2.373*	8.462*	4.854	4.692	12.134	19.407	35.069	12.409	7.014	8.841	4.526
23	2.621	2.350*	7.934	4.771	4.728	15.342	18.549	31.816	11.828	6.841	6.384	4.445
24	2.609	3.217	7.472	5.401	5.071	17.613	18.051	31.627	13.747	6.714	5.775	4.370
25	5.194	6.321	7.466	4.800	5.225	17.537	20.438	30.644	17.623	6.634	5.402	4.226
26	5.182	19.371	7.085*	4.855	5.259	18.434	25.193	29.587	12.586	6.521	5.187	4.089
27	3.329	9.625	6.808*	4.795	5.332	21.170	29.332	30.143	11.458	6.401	5.053	4.014
28	3.114	6.808	6.601*	4.765	5.316	25.829	31.314	32.138	10.646	7.318	4.994	4.261
29	3.048	7.026	6.359*	4.667		32.317	31.211	30.330	12.003	6.510	4.781	4.097
30	3.310	6.223	6.113*	4.651		37.964	32.589	28.537	10.756	6.115	4.766	4.065
31	3.237		5.894*	4.668		44.899		28.241		5.987	4.825	

MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	103.695	129.196	308.566	153.196	148.652	377.488	748.491	1034.581	546.565	287.012	179.766	145.652
TOTAL FLOW (cms days)	2.937	3.659	8.739	4.339	4.210	10.690	21.197	29.299	15.479	8.128	5.091	4.125
TOTAL DEPTH (in)	0.592	0.738	1.762	0.875	0.849	2.155	4.273	5.907	3.120	1.639	1.026	0.832
TOTAL DEPTH (cm)	1.504	1.874	4.475	2.222	2.156	5.474	10.854	15.003	7.926	4.162	2.607	2.112

ANNUAL SUMMARY:
Sum of Mean Daily Flow 4162.860 cfs = 117.892 cms
Total Depth 23.767 in = 60.367 cm
Maximum Instantaneous Flow 18.480 cfs = 0.523 cms on December 3 at 10.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 202
WATERSHED AREA: 143 ACRES (57 HECTARES)

WATER YEAR 1975
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.005*	0.011	0.005	0.010*	0.031	0.050	0.036	0.169	1.965	0.273	0.042	0.039
2	0.005*	0.011	0.005	0.010*	0.031	0.072	0.036	0.187	2.008	0.261	0.036	0.037
3	0.005*	0.009	0.006	0.010*	0.031	0.069	0.035	0.258	2.020	0.237	0.032	0.032
4	0.005*	0.007*	0.008	0.010	0.031	0.065	0.035	0.291	1.896	0.217	0.029	0.028
5	0.005*	0.005*	0.008	0.010	0.030	0.060	0.034	0.274	1.854	0.203	0.027	0.026
6	0.005*	0.003*	0.007	0.010	0.030	0.055	0.034	0.254	1.816	0.190	0.025	0.025
7	0.005*	0.005	0.008	0.010	0.030	0.053	0.033	0.320	1.638	0.178	0.037	0.023
8	0.005*	0.008	0.008	0.010	0.030	0.053	0.033	0.380	1.453	0.163	0.027	0.021
9	0.005	0.005	0.007	0.010	0.030*	0.057	0.033	0.508	1.308	0.149	0.024	0.021
10	0.005	0.005	0.007	0.010	0.030*	0.057	0.033	0.757	1.186	0.137	0.022	0.019
11	0.008	0.004	0.012	0.009	0.029*	0.055	0.035	1.102	1.108	0.126	0.019	0.018
12	0.006	0.004	0.008	0.008	0.031*	0.054	0.043	1.221	1.002	0.120	0.018	0.017
13	0.006	0.010	0.008	0.010	0.037*	0.053	0.063	1.362	0.898	0.120	0.016	0.016
14	0.005	0.007	0.009	0.033	0.036*	0.051	0.095	1.938	0.819	0.118	0.015	0.015
15	0.005	0.006	0.007	0.024	0.030*	0.050	0.146	2.710	0.748	0.113	0.013	0.015
16	0.005	0.005	0.016	0.017	0.029	0.048	0.163	2.751	0.687	0.109	0.013	0.032
17	0.005	0.005	0.012	0.243	0.028	0.047	0.156	2.418	0.651	0.101	0.031	0.036
18	0.005	0.007	0.010	0.245	0.028	0.047	0.146	2.260	0.628	0.093	0.048	0.021
19	0.005	0.010	0.010	0.085	0.027	0.049	0.139	1.950	0.604	0.087	0.047	0.017
20	0.005	0.010	0.013	0.061	0.025	0.047	0.139	1.585	0.635	0.082	0.052	0.017
21	0.020	0.010	0.028	0.049	0.025	0.045	0.153	1.312	0.587	0.077	0.033	0.016
22	0.012	0.012	0.015	0.042	0.025	0.045	0.187	1.201	0.536	0.071	0.036	0.015
23	0.010	0.007	0.011	0.053	0.026	0.044	0.214	1.303	0.493	0.065	0.155	0.014
24	0.009	0.007	0.011	0.048	0.027	0.043	0.220	1.308	0.466	0.060	0.146	0.013
25	0.008	0.018	0.010	0.043	0.027	0.043	0.224	1.123	0.458	0.052	0.062	0.013
26	0.007	0.012	0.010	0.039	0.027	0.041	0.213	0.987	0.443	0.047	0.046	0.012
27	0.007	0.008	0.010	0.037	0.027	0.039	0.203	0.979	0.439	0.043	0.039	0.012
28	0.008	0.007	0.010	0.034	0.051	0.038	0.183	1.093	0.408	0.040	0.048	0.012
29	0.008	0.005	0.010*	0.032		0.038	0.175	1.343	0.362	0.043	0.044	0.013
30	0.007	0.005	0.010*	0.031		0.038	0.171	1.615	0.282	0.041	0.039	0.013
31	0.007		0.010*	0.031		0.037		1.809		0.043	0.041	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	0.209	0.227	0.306	1.272	0.840	1.542	3.405	36.765	29.398	3.656	1.261	0.608
TOTAL FLOW (cms days)	0.006	0.006	0.009	0.036	0.024	0.044	0.096	1.041	0.833	0.104	0.036	0.017
TOTAL DEPTH (in)	0.035	0.038	0.051	0.212	0.140	0.257	0.567	6.119	4.893	0.609	0.210	0.101
TOTAL DEPTH (cm)	0.088	0.096	0.129	0.538	0.355	0.652	1.440	15.543	12.428	1.546	0.533	0.257

ANNUAL SUMMARY:
Sum of Mean Daily Flow 79.489 cfs = 2.251 cms
Total Depth 13.231 in = 33.606 cm
Maximum Instantaneous Flow 2.990 cfs = 0.085 cms on May 15 at 22.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 202
WATERSHED AREA: 143 ACRES (57 HECTARES)

WATER YEAR 1976
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.012	0.137	0.527	0.496	0.263	0.161	0.204	1.115	0.518	0.212	0.058	0.036
2	0.010	0.169	0.496	0.202	0.257	0.160	0.205	1.421	0.477	0.192	0.066	0.033
3	0.008	0.213	0.472	0.201	0.252	0.157	0.215	1.670	0.455	0.179	0.068	0.030
4	0.029	0.210	0.503	0.203	0.240	0.155	0.252	2.389	0.428	0.168	0.061	0.028
5	0.014	0.187	0.478	0.206	0.250	0.155	0.368	2.344	0.396	0.159	0.047	0.027
6	0.018	0.160	0.440	0.199	0.252	0.155	0.522	2.419	0.372	0.150	0.041	0.066
7	0.044	0.144	0.540	0.192	0.250	0.152	0.613	2.321	0.347	0.142	0.259	0.036
8	0.023	0.126	0.710	0.187	0.249	0.151	0.878	2.386	0.332	0.135	0.140	0.031
9	0.020	0.111	0.746	0.183	0.230	0.150	1.198	2.582	0.317	0.127	0.088	0.028
10	0.020	0.104	0.731	0.180	0.217	0.150	1.290	2.790	0.323	0.121	0.073	0.026
11	0.036	0.095	0.665	0.176	0.210	0.150	1.450	2.658	0.297	0.116	0.063	0.029
12	0.045	0.088	0.598	0.172	0.214	0.149	1.612	2.216	0.304	0.192	0.057	0.031
13	0.037	0.088	0.535	0.165	0.201	0.149	1.622	2.196	0.313	0.129	0.055	0.025
14	0.034	0.096	0.472	0.169	0.196	0.149	1.513	2.170	0.306	0.113	0.052	0.024
15	0.037	0.113	0.432	0.336	0.191	0.149	1.386	1.813	0.276	0.104	0.099	0.022
16	0.032	0.102	0.380	0.340	0.190	0.149	1.220	1.665	0.363	0.097	0.081	0.028
17	0.029	0.092	0.349	0.336	0.187	0.153	1.072	1.538	0.374	0.093	0.063	0.028
18	0.034	0.084*	0.323	0.356	0.182	0.160	0.949	1.356	0.323	0.104	0.076	0.024
19	0.035	0.086*	0.305	0.356	0.179	0.161	0.849	1.233	0.303	0.096	0.067	0.022
20	0.054	0.088	0.286	0.356	0.172	0.163	0.829	1.132	0.339	0.094	0.060	0.020
21	0.301	0.086	0.271	0.352	0.171	0.166	0.862	1.025	0.420	0.097	0.057	0.019
22	0.155	0.085	0.258	0.345	0.171	0.174	0.737	0.950	0.393	0.081	0.058	0.019
23	0.105	0.075	0.246	0.334	0.168	0.178	0.707	0.889	0.372	0.075	0.066	0.023
24	0.085	0.124	0.244	0.325	0.167	0.180	0.749	0.832	0.349	0.095	0.055*	0.020
25	0.081	0.097	0.237	0.314	0.164	0.177	0.797	0.858	0.333	0.080	0.094*	0.018
26	0.096	0.091	0.260	0.303	0.166	0.175	0.787	0.732	0.317	0.071	0.071*	0.017
27	0.079	0.087	0.238	0.293	0.170	0.177	0.748	0.680	0.294	0.064	0.049*	0.017
28	0.077	0.083	0.227	0.286	0.164	0.177	0.715	0.678	0.277	0.059	0.048	0.017
29	0.095	0.078	0.245	0.283	0.164	0.177	0.740	0.607	0.260	0.056	0.047	0.016
30	0.145	0.077	0.241	0.275		0.184	0.870	0.575	0.244	0.053	0.042	0.015
31	0.147		0.413	0.269		0.199		0.566		0.052	0.039	
MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	1.937	3.373	12.865	8.389	5.885	5.043	25.957	47.804	10.422	3.507	2.198	0.774
TOTAL FLOW (cms days)	0.055	0.096	0.364	0.238	0.167	0.143	0.735	1.354	0.295	0.099	0.062	0.022
TOTAL DEPTH (in)	0.322	0.561	2.141	1.396	0.979	0.839	4.320	7.957	1.735	0.584	0.366	0.129
TOTAL DEPTH (cm)	0.819	1.426	5.439	3.547	2.488	2.132	10.974	20.210	4.406	1.483	0.929	0.327

ANNUAL SUMMARY:
Sum of Mean Daily Flow 128.153 cfs = 3.629 cms
Total Depth 21.330 in = 54.179 cm
Maximum Instantaneous Flow 3.600 cfs = 0.102 cms on May 10 at 20.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 202
WATERSHED AREA: 143 ACRES (57 HECTARES)

WATER YEAR 1977
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.015	0.046	0.025	0.023	0.029	0.060	0.061	0.358	0.144	0.040	0.014	0.011
2	0.037	0.031	0.024	0.022	0.029	0.058	0.059	0.312	0.140	0.043	0.014	0.009
3	0.033	0.026	0.023	0.023	0.029	0.053	0.057	0.280	0.133	0.040	0.013	0.008
4	0.021	0.024	0.023	0.022	0.029	0.052	0.067	0.252	0.124	0.042	0.011	0.007
5	0.019	0.022	0.021	0.021	0.029	0.051	0.089	0.237	0.118	0.043	0.010	0.007
6	0.019	0.020	0.020	0.020	0.028	0.051	0.149	0.221	0.111	0.039	0.009	0.006
7	0.018	0.019	0.029	0.020	0.028	0.054	0.270	0.214	0.109	0.034	0.008	0.005
8	0.017	0.019	0.031	0.019	0.027	0.055	0.450	0.215	0.133	0.031	0.007	0.005
9	0.017	0.019	0.030	0.017	0.028	0.057	0.486	0.197	0.107	0.029	0.007	0.004
10	0.022	0.018	0.030	0.017	0.030	0.056	0.408	0.188	0.099	0.027	0.006	0.004
11	0.037	0.017	0.030	0.017	0.032	0.053	0.361	0.179	0.104	0.025	0.006	0.004
12	0.022	0.016	0.030	0.016	0.037	0.053	0.356	0.165	0.108	0.024	0.006	0.003
13	0.019	0.014	0.029	0.015	0.050	0.053	0.379	0.154	0.106	0.022	0.006	0.003
14	0.017	0.014	0.028	0.016	0.046	0.055	0.364	0.146	0.100	0.021	0.006	0.003
15	0.016	0.014	0.026	0.019	0.043	0.056	0.350	0.145	0.091	0.020	0.006	0.005
16	0.016	0.020	0.026	0.028	0.046	0.051	0.360	0.152	0.083	0.020	0.006	0.017
17	0.015	0.020	0.026	0.036	0.053	0.051	0.336	0.194	0.078	0.019	0.006	0.024
18	0.015	0.032	0.027	0.057	0.062	0.051	0.312	0.202	0.073	0.041	0.006	0.009
19	0.014	0.022	0.024	0.053	0.066	0.051	0.296	0.237	0.069	0.024	0.006*	0.009
20	0.013	0.020	0.022	0.041	0.076	0.050	0.282	0.233	0.072	0.021	0.006*	0.027
21	0.013	0.019	0.022	0.039	0.083	0.054	0.294	0.222	0.066	0.020	0.006*	0.023
22	0.013	0.019	0.022	0.037	0.077	0.056	0.365	0.207	0.062	0.019	0.005*	0.012
23	0.012	0.019	0.022	0.036	0.071	0.062	0.518	0.202	0.059	0.018	0.007*	0.009
24	0.012	0.021	0.022	0.034	0.066	0.065	0.662	0.204	0.055	0.038	0.011	0.011
25	0.027	0.028	0.023	0.033	0.062	0.059	0.696	0.195	0.052	0.030	0.014	0.015
26	0.022	0.017	0.030	0.033	0.061	0.060	0.594	0.183	0.048	0.024	0.037	0.013
27	0.017	0.011	0.030	0.032	0.058	0.065	0.485	0.181	0.045	0.021	0.025	0.010
28	0.017	0.010	0.028	0.032	0.061	0.063	0.437	0.181	0.043	0.019	0.015	0.018
29	0.016	0.011	0.027	0.032		0.062	0.399	0.172	0.041	0.017	0.016	0.031
30	0.015	0.021	0.025	0.031		0.061	0.362	0.160	0.039	0.016	0.054	0.031
31	0.015		0.025	0.030		0.061		0.151		0.015	0.021	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	0.581	0.609	0.798	0.869	1.340	1.737	10.305	6.335	2.611	0.843	0.370	0.343
TOTAL FLOW (cms days)	0.016	0.017	0.023	0.025	0.038	0.049	0.292	0.179	0.074	0.024	0.010	0.010
TOTAL DEPTH (in)	0.097	0.101	0.133	0.145	0.223	0.289	1.715	1.054	0.435	0.140	0.062	0.057
TOTAL DEPTH (cm)	0.246	0.257	0.337	0.367	0.567	0.734	4.357	2.678	1.104	0.356	0.157	0.145

ANNUAL SUMMARY:
Sum of Mean Daily Flow 26.740 cfs = 0.757 cms
Total Depth 4.451 in = 11.305 cm
Maximum Instantaneous Flow 0.740 cfs = 0.021 cms on April 24 at 15.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 202
WATERSHED AREA: 143 ACRES (57 HECTARES)

WATER YEAR 1978
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.024	0.030	0.130	0.128*	0.091	0.207	1.861	0.701*	0.487	0.148	0.044	0.019
2	0.018	0.054	1.036	0.122*	0.092	0.203	1.575	0.708*	0.459	0.148	0.042	0.018
3	0.014	0.034	0.664	0.117*	0.102	0.197	1.344	0.762*	0.428	0.145	0.040	0.017
4	0.012	0.031	0.443	0.113*	0.103	0.196	1.172	0.695*	0.397	0.242	0.037	0.016
5	0.012	0.032	0.335	0.107*	0.106	0.196	1.020	0.628	0.378	0.203	0.036	0.016
6	0.014	0.031	0.286	0.103*	0.124	0.189	0.964	0.593	0.354	0.177	0.034	0.018
7	0.042	0.028	0.251	0.099*	0.118	0.185	0.901	0.561	0.326	0.220	0.032	0.035
8	0.032	0.024	0.214	0.106	0.118	0.193	0.835	0.540	0.306	0.200	0.029	0.031
9	0.048	0.022	0.195	0.108	0.116	0.231	0.789	0.553	0.294	0.178	0.028	0.022
10	0.037	0.024	0.181	0.106	0.117	0.239	0.796	0.633	0.329	0.169	0.028	0.020
11	0.031	0.025	0.199	0.102	0.117	0.256	0.880	0.676	0.297	0.160	0.025	0.027
12	0.027	0.025	0.184	0.100	0.117	0.264	0.804*	0.637	0.262	0.149	0.024	0.062
13	0.022	0.027	0.266	0.099	0.117	0.263	0.580*	0.637	0.244	0.137	0.040	0.040
14	0.020	0.040	0.381	0.098	0.117	0.254	0.508*	0.623	0.230	0.127	0.039	0.033
15	0.018	0.071	0.523	0.101	0.117	0.245	0.525*	0.622	0.219	0.125	0.047	0.029
16	0.015	0.055	0.542	0.101	0.115	0.240	0.518*	0.608	0.207	0.118	0.066	0.025
17	0.014	0.043*	0.484	0.101	0.111	0.246	0.484*	0.580	0.194	0.111	0.063	0.024
18	0.012	0.038*	0.425	0.106	0.108	0.290	0.475*	0.554	0.196	0.106	0.046	0.026
19	0.011	0.035*	0.372	0.105	0.109	0.382	0.480*	0.523	0.184	0.098	0.039	0.029
20	0.011	0.033	0.328	0.101	0.118	0.494	0.475*	0.504	0.166	0.090	0.036	0.023
21	0.011	0.032	0.296	0.099	0.119	0.617	0.444*	0.494	0.156	0.084	0.034	0.023
22	0.010	0.031	0.268	0.101	0.118	0.785	0.428*	0.519	0.149	0.080	0.094	0.021
23	0.010	0.031	0.248	0.101	0.122	0.965	0.416*	0.526	0.143	0.077	0.053	0.020
24	0.010	0.030	0.222	0.098	0.145	1.022	0.408*	0.599	0.172	0.070	0.041	0.019
25	0.051	0.167	0.208	0.099	0.173	0.978	0.448*	0.612	0.235	0.065	0.038	0.018
26	0.043	0.178	0.194	0.099	0.191	1.004	0.494*	0.616	0.162	0.059	0.034	0.016
27	0.025	0.102	0.184	0.099	0.201	1.192	0.506*	0.617	0.142	0.056	0.032	0.015
28	0.021	0.086	0.168	0.097	0.207	1.449	0.521*	0.590	0.132	0.067	0.030	0.016
29	0.019	0.145	0.158	0.096		1.670	0.543*	0.579	0.210	0.060	0.028	0.017
30	0.025	0.115	0.145	0.091		1.860	0.601*	0.543	0.174	0.053	0.026	0.015
31	0.021		0.135*	0.090		1.939		0.516		0.048	0.023	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	0.679	1.616	9.663	3.189	3.507	18.452	21.791	18.546	7.632	3.769	1.209	0.713
TOTAL FLOW (cms days)	0.019	0.046	0.274	0.090	0.099	0.523	0.617	0.525	0.216	0.107	0.034	0.020
TOTAL DEPTH (in)	0.113	0.269	1.608	0.531	0.584	3.071	3.627	3.087	1.270	0.627	0.201	0.119
TOTAL DEPTH (cm)	0.287	0.683	4.085	1.348	1.483	7.801	9.213	7.841	3.226	1.593	0.511	0.301

ANNUAL SUMMARY:
Sum of Mean Daily Flow 90.767 cfs = 2.571 cms
Total Depth 15.108 in = 38.373 cm
Maximum Instantaneous Flow 1.970 cfs = 0.056 cms on March 31 at 22.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 202
WATERSHED AREA: 143 ACRES (57 HECTARES)

WATER YEAR 1979
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.015	0.005	0.014	0.017	0.017	0.024	0.174	1.255	0.244	0.059	0.006	0.014*
2	0.014	0.005	0.014	0.017	0.017	0.025	0.158	1.248	0.225	0.060	0.006	0.011*
3	0.013	0.005	0.015	0.017	0.017	0.025	0.142	1.212	0.208	0.054	0.005	0.008*
4	0.011	0.005	0.030	0.017	0.017	0.025	0.136	1.321	0.192	0.050	0.005	0.008*
5	0.009	0.005	0.019	0.017	0.017	0.029	0.140	1.444	0.183	0.047	0.005	0.007*
6	0.008	0.005	0.017	0.017	0.017	0.079	0.160	1.264	0.188	0.044	0.005	0.006*
7	0.008	0.005	0.013	0.017	0.017	0.131	0.229	1.083	0.178	0.041	0.005	0.006*
8	0.008	0.074	0.016	0.017	0.017	0.107	0.262	0.969	0.160	0.038	0.004	0.005*
9	0.008	0.023	0.018	0.017	0.026	0.086	0.292	0.868	0.146	0.035	0.003	0.006*
10	0.007	0.011	0.018	0.017	0.026	0.075	0.290	0.795	0.134	0.032	0.003	0.011*
11	0.007	0.008	0.019	0.017	0.026	0.070	0.274	0.754	0.124	0.030	0.003	0.005*
12	0.007	0.006	0.019	0.017	0.029	0.072	0.253	0.724	0.116	0.028	0.003	0.004*
13	0.007	0.006	0.019	0.017	0.067	0.076	0.241	0.730	0.111	0.027	0.003	0.004*
14	0.007	0.006	0.019	0.017	0.049	0.078	0.230	0.740	0.104	0.026	0.003	0.003*
15	0.007	0.006	0.019	0.017	0.039	0.091	0.223	0.761	0.100	0.025	0.007	0.003*
16	0.007	0.006	0.019	0.017	0.036	0.112	0.244	0.734	0.097	0.023	0.006	0.003*
17	0.006	0.008	0.019	0.017	0.032	0.113	0.361	0.667	0.100	0.021	0.005	0.002*
18	0.006	0.008	0.019	0.017	0.030	0.108	0.386	0.618	0.121	0.020	0.014	0.002*
19	0.006	0.009	0.018	0.017	0.028	0.103	0.371	0.566	0.107	0.017	0.012	0.002*
20	0.006	0.009	0.018	0.017	0.027	0.101	0.334	0.522	0.096	0.015	0.010	0.002*
21	0.006	0.009	0.018	0.017	0.025	0.101	0.314	0.479	0.176	0.015	0.011	0.002*
22	0.006	0.009	0.019	0.017	0.025	0.100	0.326	0.446	0.114	0.014	0.008	0.002*
23	0.005	0.010	0.020	0.017	0.025	0.101	0.371	0.416	0.094	0.014	0.030	0.001*
24	0.005	0.012	0.017	0.017	0.025	0.116	0.433	0.439	0.085	0.013	0.013	0.001*
25	0.005	0.012	0.019	0.017	0.024	0.140	0.489	0.376	0.078	0.012	0.007	0.001*
26	0.005	0.011	0.019	0.017	0.024	0.142	0.562	0.350	0.071	0.010	0.009	0.002*
27	0.005	0.011	0.019	0.017	0.024	0.151	0.703	0.332	0.067	0.009	0.007	0.001*
28	0.005	0.012	0.019	0.017	0.024	0.193	0.900	0.321	0.059	0.009	0.005	0.001*
29	0.005	0.012	0.018	0.017		0.221	1.096	0.298	0.057	0.009	0.006	0.001*
30	0.005	0.013	0.017	0.017		0.216	1.215	0.278	0.058	0.008	0.037*	0.001*
31	0.005		0.017	0.017		0.193		0.261		0.007	0.055*	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	0.222	0.326	0.558	0.515	0.743	3.201	11.307	22.268	3.790	0.810	0.295	0.126
TOTAL FLOW (cms days)	0.006	0.009	0.016	0.015	0.021	0.091	0.320	0.631	0.107	0.023	0.008	0.004
TOTAL DEPTH (in)	0.037	0.054	0.093	0.086	0.124	0.533	1.882	3.706	0.631	0.135	0.049	0.021
TOTAL DEPTH (cm)	0.094	0.138	0.236	0.218	0.314	1.353	4.780	9.414	1.602	0.342	0.125	0.053

ANNUAL SUMMARY:

Sum of Mean Daily Flow 44.161 cfs = 1.251 cms
Total Depth 7.350 in = 18.670 cm
Maximum Instantaneous Flow 1.530 cfs = 0.043 cms on May 4 at 23.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 202
WATERSHED AREA: 143 ACRES (57 HECTARES)

WATER YEAR 1980
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.001	0.006	0.012	0.016*	0.024*	0.124	0.046	0.381	0.512	0.226	0.061	0.017
2	0.001	0.005	0.040	0.014*	0.024*	0.117	0.045	0.738	0.591	0.334	0.058	0.036
3	0.001	0.005	0.048	0.014*	0.031*	0.115	0.045	0.708	0.556	0.355	0.056	0.023
4	0.001	0.006	0.076	0.013*	0.026*	0.130	0.045	0.620	0.572	0.325	0.053	0.019
5	0.001	0.009	0.048	0.012*	0.023*	0.129	0.050	0.548	0.554	0.308	0.047	0.017
6	0.001	0.008	0.039	0.012*	0.022*	0.114	0.054	0.494	0.553	0.291	0.043	0.017
7	0.001	0.006	0.052	0.011*	0.022*	0.107	0.052	0.433	0.516	0.266	0.041	0.016
8	0.001	0.006	0.048	0.011*	0.021*	0.100	0.052	0.396	0.478	0.247	0.040	0.014
9	0.001	0.005	0.053	0.011*	0.021*	0.094	0.059	0.376	0.450	0.272	0.038	0.014
10	0.001	0.005	0.070	0.011*	0.022*	0.094	0.065	0.359	0.449	0.248	0.036	0.028
11	0.001	0.005	0.059	0.012*	0.022*	0.096	0.078	0.324	0.434	0.220	0.034	0.035
12	0.001	0.004	0.039	0.038*	0.021*	0.092	0.087	0.292	0.449	0.205	0.031	0.017
13	0.001	0.004	0.035	0.064*	0.021*	0.089	0.132	0.270	0.449	0.194	0.026	0.050
14	0.001	0.003	0.035	0.089*	0.022*	0.085	0.231	0.252	0.456	0.221	0.025	0.032
15	0.008	0.003	0.035	0.068*	0.027*	0.078	0.304	0.269	0.476	0.192	0.022	0.020
16	0.006	0.002	0.032	0.053*	0.032	0.072	0.337	0.259	0.458	0.170	0.021	0.018
17	0.011	0.012	0.081	0.047*	0.034	0.071	0.457	0.243	0.435	0.155	0.021	0.016
18	0.014	0.008	0.075	0.041*	0.035	0.067	0.644	0.222	0.412	0.148	0.056	0.041
19	0.034	0.007	0.063	0.036*	0.043	0.066	0.780	0.205	0.384	0.139	0.031	0.030
20	0.009	0.006	0.059	0.033*	0.053	0.065	0.873	0.191	0.355	0.132	0.027	0.134
21	0.009	0.005	0.054	0.031*	0.050	0.064	0.867	0.182	0.329	0.124	0.025	0.097
22	0.009	0.006	0.047	0.029*	0.051	0.062	0.807	0.186	0.320	0.115	0.024	0.050
23	0.010	0.006	0.046	0.028*	0.051	0.061	0.801	0.201	0.296	0.104	0.022	0.040
24	0.008	0.006	0.039	0.028*	0.049	0.059	0.845	0.215	0.275	0.094	0.021	0.035
25	0.010	0.007	0.037	0.025*	0.048	0.056	0.692	0.349	0.251	0.090	0.020	0.030
26	0.009	0.007	0.035	0.024*	0.050	0.056	0.654	0.529	0.254	0.083	0.017	0.026
27	0.007	0.008	0.029*	0.024*	0.076	0.052	0.610	0.600	0.263	0.078	0.016	0.023
28	0.007	0.012	0.024*	0.024*	0.128	0.051	0.561	0.574	0.224	0.074	0.016	0.020
29	0.007	0.021	0.021*	0.025*	0.132	0.050	0.502	0.539	0.203	0.070	0.014	0.019
30	0.007	0.012	0.019*	0.025*		0.048	0.417	0.525	0.190	0.069	0.014	0.017
31	0.006		0.017*	0.024*		0.046		0.492		0.064	0.016	
MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	0.184	0.203	1.365	0.891	1.181	2.507	11.191	11.970	12.144	5.610	0.971	0.948
TOTAL FLOW (cms days)	0.005	0.006	0.039	0.025	0.033	0.071	0.317	0.339	0.344	0.159	0.028	0.027
TOTAL DEPTH (in)	0.031	0.034	0.227	0.148	0.197	0.417	1.863	1.992	2.021	0.934	0.162	0.158
TOTAL DEPTH (cm)	0.078	0.086	0.577	0.377	0.499	1.060	4.731	5.060	5.134	2.372	0.411	0.401

ANNUAL SUMMARY:
Sum of Mean Daily Flow 49.164 cfs = 1.392 cms
Total Depth 8.183 in = 20.785 cm
Maximum Instantaneous Flow 2.600 cfs = 0.074 cms on May 2 at 16.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 202
WATERSHED AREA: 143 ACRES (57 HECTARES)

WATER YEAR 1981
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.016	0.008	0.014	0.237	0.067*	0.211	0.301	0.280	0.252*	0.380	0.050	0.020
2	0.013	0.010	0.024	0.213	0.053*	0.208	0.291	0.271	0.244*	0.348	0.046	0.017
3	0.013	0.009	0.042	0.191	0.051*	0.197	0.293	0.254	0.239*	0.318	0.042	0.013
4	0.012	0.008	0.050	0.170	0.051*	0.196	0.277	0.249	0.252*	0.290	0.039	0.011
5	0.012	0.007	0.037	0.155	0.050*	0.195	0.285	0.235*	0.278*	0.269	0.039	0.010
6	0.012	0.023	0.031	0.141	0.050*	0.195	0.274	0.212*	0.331*	0.324	0.038	0.008
7	0.011	0.074	0.025	0.129	0.050*	0.191	0.261	0.198*	0.335*	0.347	0.035	0.008
8	0.011	0.037	0.018	0.121	0.050*	0.191	0.256	0.192*	0.555*	0.259	0.032	0.007
9	0.010	0.034	0.017	0.118	0.050*	0.192	0.251	0.184*	0.649*	0.231	0.029	0.006
10	0.009	0.032	0.018	0.108	0.051*	0.195	0.244	0.185*	0.691*	0.215	0.026	0.005
11	0.010	0.025	0.019	0.101	0.049*	0.199	0.240	0.203*	0.650	0.200	0.024	0.005
12	0.011	0.020	0.019	0.095	0.057	0.207	0.231	0.184*	0.794	0.184	0.022	0.005
13	0.014	0.016	0.018	0.088	0.068	0.220	0.218	0.173*	0.882	0.171	0.021	0.005
14	0.013	0.012	0.016	0.082	0.112	0.232	0.226	0.172*	0.953	0.159	0.020	0.005
15	0.013	0.011	0.023	0.076	0.081	0.247	0.270	0.194*	0.875	0.147	0.019	0.005
16	0.012	0.009	0.029	0.073	0.230	0.273	0.306	0.179*	1.033	0.137	0.017	0.004
17	0.012	0.010	0.037	0.068	0.226	0.260	0.330	0.174*	1.107	0.125	0.016	0.004
18	0.012	0.012	0.035	0.067	0.236	0.250	0.363	0.166*	1.094	0.123	0.015	0.004
19	0.011	0.012	0.030	0.066	0.264	0.248	0.387	0.163*	1.193	0.113	0.013	0.011
20	0.011	0.012	0.028	0.065	0.261	0.248	0.388	0.162*	1.280	0.107	0.012	0.013
21	0.011	0.020	0.044	0.063	0.255	0.238	0.380	0.270*	1.181	0.101	0.012	0.010
22	0.011	0.030	0.143	0.062	0.248	0.242	0.378	0.232*	1.049	0.095	0.012	0.008
23	0.011	0.013	0.107	0.104	0.240	0.245	0.377	0.295*	0.919	0.089	0.011	0.007
24	0.011	0.012	0.118	0.098	0.234	0.240	0.379	0.285*	0.803	0.083	0.010	0.005
25	0.011	0.009	0.456	0.078	0.227	0.286	0.359	0.323*	0.708	0.085	0.010	0.016
26	0.014	0.011	0.893	0.073	0.222	0.304	0.350	0.301*	0.628	0.080	0.009	0.013
27	0.012	0.014	0.658	0.074	0.220	0.313	0.342	0.296*	0.560	0.073	0.008	0.048
28	0.011	0.019	0.500	0.077	0.216	0.312	0.336	0.288*	0.505	0.068	0.007	0.051
29	0.009	0.016	0.364	0.075		0.312	0.314	0.275*	0.455	0.062	0.007	0.030
30	0.009	0.016	0.319	0.072		0.296	0.295	0.299*	0.413	0.056	0.042	0.024
31	0.008		0.269	0.069		0.316		0.278*		0.053	0.019	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	0.352	0.540	4.402	3.210	3.965	7.457	9.198	7.171	20.907	5.289	0.701	0.377
TOTAL FLOW (cms days)	0.010	0.015	0.125	0.091	0.112	0.211	0.261	0.203	0.592	0.150	0.020	0.011
TOTAL DEPTH (in)	0.059	0.090	0.733	0.534	0.660	1.241	1.531	1.194	3.480	0.880	0.117	0.063
TOTAL DEPTH (cm)	0.149	0.228	1.861	1.357	1.676	3.153	3.889	3.032	8.839	2.236	0.296	0.159

ANNUAL SUMMARY:
Sum of Mean Daily Flow 63.569 cfs = 1.800 cms
Total Depth 10.581 in = 26.875 cm
Maximum Instantaneous Flow 1.550 cfs = 0.044 cms on June 20 at 2.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 202
WATERSHED AREA: 143 ACRES (57 HECTARES)

WATER YEAR 1982
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.023	0.027	0.029	0.034	0.045	0.174	0.228	1.081	0.835	0.291	0.053	0.021
2	0.021	0.026	0.055	0.032	0.044	0.173	0.225	1.359	0.813	0.245	0.061	0.019
3	0.020	0.025	0.035	0.030	0.044	0.173	0.222	1.568	0.826	0.241	0.056	0.015
4	0.019	0.019	0.029	0.030	0.044	0.174	0.213	1.415	0.783	0.225	0.054	0.014
5	0.014	0.017	0.037	0.030	0.045	0.169	0.206	1.210	0.726	0.233	0.051	0.013
6	0.014	0.017	0.073	0.031	0.045	0.167	0.193	1.056	0.689	0.212	0.047	0.012
7	0.019	0.017	0.062	0.031	0.045	0.167	0.187	1.056	0.704	0.212	0.044	0.011
8	0.020	0.017	0.049	0.031	0.045	0.162	0.181	1.090	0.634	0.211	0.041	0.009
9	0.044	0.017	0.062	0.030	0.045	0.173	0.176	1.067	0.594	0.203	0.040	0.009
10	0.061	0.017	0.083	0.030	0.045	0.191	0.172	1.016	0.565	0.187	0.038	0.050
11	0.070	0.017	0.055	0.031	0.046	0.239	0.215	0.991	0.545	0.172	0.037	0.026
12	0.049	0.036	0.047	0.028	0.043	0.256	0.310	1.017	0.570	0.162	0.036	0.034
13	0.036	0.035	0.042	0.028	0.044	0.255	0.396	1.117	0.550	0.172	0.033	0.025
14	0.030	0.031	0.039	0.030	0.146	0.254	0.481	1.358	0.529	0.184	0.033	0.020
15	0.028	0.026	0.037	0.031	0.132	0.252	0.494	1.510	0.470	0.149	0.032	0.018
16	0.027	0.027	0.035	0.029	0.202	0.242	0.481	1.542	0.440	0.152	0.031	0.016
17	0.025	0.047	0.032	0.031	0.196	0.235	0.450	1.621	0.413	0.139	0.029	0.015
18	0.024	0.041	0.032	0.032	0.201	0.226	0.416	1.693	0.390	0.128	0.028	0.014
19	0.023	0.034	0.160	0.031	0.221	0.213	0.386	1.507	0.366	0.120	0.025	0.013
20	0.021	0.031	0.091	0.030	0.279	0.201	0.357	1.392	0.341	0.113	0.034	0.012
21	0.020	0.046	0.070	0.028	0.363	0.193	0.337	1.413	0.318	0.105	0.035	0.011
22	0.020	0.056	0.058	0.028	0.352	0.185	0.362	1.476	0.298	0.101	0.029	0.011
23	0.020	0.043	0.053	0.038	0.307	0.179	0.524	1.446	0.287	0.094	0.026	0.011
24	0.020	0.041	0.050	0.070	0.262	0.177	0.725	1.389	0.267	0.088	0.023	0.010
25	0.020	0.037	0.047	0.052	0.232	0.178	0.822	1.438	0.248	0.084	0.020	0.010
26	0.039	0.035	0.045	0.048	0.209	0.183	0.845	1.423	0.230	0.080	0.019	0.032
27	0.031	0.033	0.041	0.047	0.190	0.195	0.879	1.252	0.227	0.074	0.018	0.041
28	0.027	0.029	0.041	0.047	0.176	0.205	0.996	1.162	0.270	0.069	0.016	0.071
29	0.025	0.034	0.040	0.046		0.215	1.043	1.046	0.248	0.064	0.015	0.037
30	0.025	0.030	0.037	0.045		0.219	1.025	0.944	0.218	0.059	0.029	0.027
31	0.026		0.036	0.045		0.222		0.876		0.055	0.025	
MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	0.858	0.905	1.603	1.100	4.049	6.246	13.545	39.529	14.393	4.622	1.057	0.628
TOTAL FLOW (cms days)	0.024	0.026	0.045	0.031	0.115	0.177	0.384	1.119	0.408	0.131	0.030	0.018
TOTAL DEPTH (in)	0.143	0.151	0.267	0.183	0.674	1.040	2.254	6.579	2.396	0.769	0.176	0.104
TOTAL DEPTH (cm)	0.363	0.383	0.678	0.465	1.712	2.641	5.726	16.712	6.085	1.954	0.447	0.265

ANNUAL SUMMARY:
Sum of Mean Daily Flow 88.534 cfs = 2.507 cms
Total Depth 14.736 in = 37.430 cm
Maximum Instantaneous Flow 1.720 cfs = 0.049 cms on May 17 at 23.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 202
WATERSHED AREA: 143 ACRES (57 HECTARES)

WATER YEAR 1983
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.024	0.035	0.024	0.024	0.050	0.214	0.175	0.195	0.118	0.101	0.023	0.013
2	0.021	0.031	0.023	0.023	0.048	0.237	0.177	0.191	0.115	0.105	0.020	0.019
3	0.052	0.028	0.030	0.023	0.045	0.259	0.172	0.182	0.111	0.085	0.018	0.013
4	0.033	0.027	0.057	0.024	0.042	0.289	0.169	0.174	0.105	0.067	0.017	0.010
5	0.030	0.027	0.039	0.089	0.038	0.305	0.162	0.207	0.099	0.060	0.017	0.009
6	0.026	0.035	0.037	0.091	0.037	0.326	0.160	0.203	0.094	0.053	0.015	0.008
7	0.041	0.029	0.033	0.129	0.037	0.337	0.160	0.175	0.089	0.048	0.014	0.006
8	0.046	0.027	0.029	0.120	0.037	0.335	0.158	0.187	0.086	0.045	0.014	0.005
9	0.038	0.026	0.029	0.100	0.037	0.362	0.157	0.182	0.083	0.046	0.037	0.005
10	0.034	0.026	0.028	0.087	0.035	0.407	0.151	0.194	0.089	0.062	0.030	0.027
11	0.031	0.024	0.027	0.078	0.037	0.436	0.143	0.188	0.092	0.047	0.032	0.026
12	0.028	0.023	0.027	0.073	0.044	0.427	0.142	0.177	0.111	0.041	0.018	0.014
13	0.027	0.022	0.027	0.070	0.047	0.425	0.135	0.177	0.093	0.037	0.017	0.011
14	0.025	0.021	0.026	0.066	0.046	0.400	0.133	0.177	0.080	0.099	0.020	0.010
15	0.024	0.020	0.026	0.063	0.044	0.376	0.130	0.198	0.085	0.055	0.018	0.008
16	0.023	0.020	0.035	0.061	0.055	0.342	0.134	0.204	0.073	0.048	0.016	0.007
17	0.021	0.023	0.038	0.059	0.085	0.321	0.158	0.217	0.089	0.042	0.014	0.007
18	0.021	0.026	0.033	0.056	0.180	0.294	0.185	0.237	0.104	0.039	0.011	0.011
19	0.021	0.029	0.032	0.055	0.147	0.265	0.206	0.232	0.081	0.036	0.017	0.016
20	0.021	0.027	0.031	0.052	0.144	0.243	0.225	0.217	0.075	0.046	0.013	0.013
21	0.020	0.026	0.031	0.051	0.137	0.231	0.237	0.210	0.067	0.039	0.011	0.011
22	0.020	0.032	0.031	0.050	0.142	0.219	0.238	0.200	0.063	0.036	0.013	0.009
23	0.020	0.033	0.031	0.046	0.150	0.208	0.256	0.190	0.060	0.034	0.016	0.008
24	0.020	0.022	0.031	0.046	0.173	0.195	0.311	0.182	0.055	0.035	0.013	0.007
25	0.020	0.021	0.028	0.043	0.204	0.191	0.271	0.173	0.052	0.034	0.011	0.007
26	0.028	0.021	0.028	0.042	0.227	0.181	0.245	0.165	0.048	0.032	0.010	0.006
27	0.033	0.021	0.028	0.050	0.226	0.174	0.225	0.161	0.054	0.029	0.009	0.005
28	0.028	0.021	0.028	0.055	0.219	0.166	0.214	0.150	0.057	0.028	0.008	0.005
29	0.045	0.022	0.027	0.053		0.166	0.203	0.140	0.061	0.027	0.007	0.005
30	0.044	0.024	0.027	0.053		0.187	0.199	0.131	0.057	0.027	0.006	0.005
31	0.035		0.025	0.051		0.179		0.124		0.025	0.006	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	0.896	0.769	0.946	1.884	2.711	8.696	5.629	5.738	2.445	1.508	0.490	0.303
TOTAL FLOW (cms days)	0.025	0.022	0.027	0.053	0.077	0.246	0.159	0.163	0.069	0.043	0.014	0.009
TOTAL DEPTH (in)	0.149	0.128	0.157	0.313	0.451	1.447	0.937	0.955	0.407	0.251	0.082	0.050
TOTAL DEPTH (cm)	0.379	0.325	0.400	0.796	1.146	3.676	2.380	2.426	1.034	0.637	0.207	0.128

ANNUAL SUMMARY:
Sum of Mean Daily Flow 32.013 cfs = 0.907 cms
Total Depth 5.328 in = 13.534 cm
Maximum Instantaneous Flow 0.460 cfs = 0.013 cms on March 11 at 15.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 202
WATERSHED AREA: 143 ACRES (57 HECTARES)

WATER YEAR 1984
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.006	0.011	0.019	0.015	0.075	0.057	0.212	0.524	1.123	0.233	0.076	0.025
2	0.006	0.022	0.019	0.017	0.069	0.060	0.204	0.582	1.027	0.216	0.073	0.019
3	0.006	0.017	0.019	0.218	0.068	0.057	0.200	0.592	0.934	0.202	0.070	0.016
4	0.007	0.030	0.019	0.188	0.067	0.055	0.207	0.597	0.919	0.190	0.068	0.014
5	0.007	0.020	0.018	0.166	0.064	0.054	0.263	0.583	0.863	0.180	0.066	0.013
6	0.007	0.040	0.018	0.173	0.062	0.055	0.334	0.554	0.845	0.168	0.064	0.025
7	0.007	0.025	0.017	0.158	0.062	0.054	0.348	0.527	0.952	0.157	0.062	0.020
8	0.007	0.022	0.018	0.136	0.061	0.056	0.370	0.563	0.947	0.149	0.061	0.023
9	0.021	0.020	0.018	0.114	0.058	0.067	0.377	0.931	0.928	0.138	0.060	0.021
10	0.019	0.019	0.044	0.100	0.056	0.087	0.376	0.982	0.879	0.129	0.059	0.018
11	0.016	0.036	0.030	0.090	0.055	0.109	0.357	0.987	0.913	0.122	0.056	0.015
12	0.013	0.038	0.027	0.083	0.061	0.114	0.339	1.173	0.827	0.115	0.055	0.013
13	0.011	0.035	0.026	0.077	0.114	0.124	0.318	1.406	0.777	0.110	0.053	0.012
14	0.011	0.027	0.026	0.071	0.098	0.207	0.344	1.781	0.722	0.103	0.052	0.011
15	0.010	0.029	0.024	0.065	0.088	0.214	0.566	1.638	0.673	0.098	0.051	0.011
16	0.010	0.029	0.023	0.060	0.084	0.225	1.070	1.437	0.618	0.092	0.050	0.010
17	0.014	0.033	0.023	0.054	0.085	0.226	1.576	1.296	0.567	0.086	0.049	0.009
18	0.023	0.030	0.022	0.051	0.081	0.215	1.640	1.293	0.524	0.084	0.047	0.009
19	0.018	0.026	0.022	0.046	0.076	0.229	1.541	1.363	0.478	0.080	0.046	0.009
20	0.015	0.025	0.022	0.041	0.073	0.344	1.277	1.513	0.459	0.074	0.045	0.049
21	0.013	0.023	0.020	0.038	0.071	0.438	1.105	1.358	0.535	0.070	0.043	0.037
22	0.023	0.021	0.018	0.036	0.070	0.434	1.033	1.207	0.433	0.065	0.038	0.028
23	0.028	0.020	0.017	0.032	0.066	0.402	1.101	1.466	0.396	0.062	0.035	0.030
24	0.020	0.024	0.023	0.140	0.065	0.373	1.044	1.304	0.373	0.061	0.034	0.026
25	0.018	0.023	0.017	0.147	0.062	0.337	0.914	1.181	0.365	0.055	0.034	0.022
26	0.016	0.022	0.015	0.095	0.061	0.311	0.786	1.268	0.329	0.054	0.032	0.019
27	0.014	0.022	0.014	0.087	0.060	0.281	0.691	1.237	0.307	0.060	0.032	0.017
28	0.013	0.022	0.014	0.085	0.059	0.262	0.625	1.231	0.286	0.088	0.028	0.015
29	0.012	0.021	0.013	0.082	0.057	0.245	0.557	1.272	0.271	0.088	0.019	0.014
30	0.012	0.019	0.014	0.079		0.231	0.535	1.380	0.253	0.085	0.015	0.013
31	0.012		0.015	0.075		0.221		1.247		0.080	0.029	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	0.416	0.749	0.633	2.818	2.026	6.143	20.312	34.469	19.519	3.489	1.501	0.562
TOTAL FLOW (cms days)	0.012	0.021	0.018	0.080	0.057	0.174	0.575	0.976	0.553	0.099	0.043	0.016
TOTAL DEPTH (in)	0.069	0.125	0.105	0.469	0.337	1.022	3.381	5.737	3.249	0.581	0.250	0.094
TOTAL DEP1H (cm)	0.176	0.317	0.268	1.192	0.857	2.597	8.587	14.572	8.252	1.475	0.635	0.238

ANNUAL SUMMARY:
Sum of Mean Daily Flow 92.637 cfs = 2.623 cms
Total Depth 15.419 in = 39.164 cm
Maximum Instantaneous Flow 1.890 cfs = 0.054 cms on May 14 at 13.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 204
WATERSHED AREA: 348 ACRES (140 HECTARES)

WATER YEAR 1975
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.069*	0.111	0.088	0.067	0.119	0.201	0.145	0.405	7.441	0.937	0.226	0.203
2	0.069*	0.098	0.088	0.066	0.120	0.243	0.145	0.461	8.091	0.889	0.211	0.187
3	0.069*	0.093	0.086	0.067	0.121	0.227	0.143	0.609	8.197	0.832	0.204	0.173
4	0.069*	0.091	0.081	0.068	0.122	0.219	0.142	0.619	7.135	0.764	0.197	0.163
5	0.069*	0.094	0.073	0.068	0.123	0.206	0.140	0.591	6.792	0.718	0.189	0.154
6	0.069*	0.100	0.069	0.069	0.123	0.195	0.140	0.554	7.044	0.677	0.181	0.149
7	0.069*	0.110	0.069	0.069	0.123	0.192	0.139	0.697	6.550	0.636	0.238	0.142
8	0.069*	0.111	0.065	0.068	0.123	0.193	0.137	0.829	5.643	0.595	0.185	0.139
9	0.069*	0.096	0.065	0.068	0.122	0.203	0.135	1.034	4.908	0.554	0.175	0.133
10	0.069*	0.096	0.066	0.071	0.122	0.199	0.140	1.422	4.355	0.513	0.167	0.129
11	0.092	0.091	0.080	0.071	0.120	0.194	0.154	2.118	4.082	0.478	0.160	0.125
12	0.080	0.116	0.069	0.068	0.122	0.187	0.183	2.519	3.916	0.450	0.156	0.122
13	0.075	0.126	0.069	0.076	0.128	0.180	0.227	2.794	3.606	0.437	0.148	0.118
14	0.073	0.100	0.069	0.093	0.127	0.176	0.276	3.770	3.215	0.425	0.143	0.114
15	0.072	0.094	0.069	0.104	0.123	0.173	0.371	6.009	2.920	0.412	0.138	0.111
16	0.070	0.092	0.103	0.089	0.122	0.170	0.387	6.504	2.565	0.384	0.140	0.185
17	0.067	0.097	0.077	0.639	0.120	0.167	0.359	5.574	2.241	0.348	0.221	0.217
18	0.066	0.118	0.077	0.821	0.119	0.169	0.345	5.119	2.043	0.330	0.275	0.140
19	0.066	0.111	0.077	0.280	0.121	0.175	0.334	4.563	1.904	0.319	0.244	0.124
20	0.068	0.130	0.093	0.212	0.119	0.169	0.347	3.696	1.929	0.307	0.250	0.116
21	0.129	0.140	0.111	0.180	0.114	0.168	0.376	2.975	1.836	0.293	0.187	0.110
22	0.117	0.140	0.079	0.161	0.113	0.166	0.434	2.821	1.678	0.274	0.198	0.107
23	0.097	0.107	0.073	0.175	0.119	0.162	0.488	3.388	1.541	0.259	0.619	0.106
24	0.090	0.134	0.071	0.189	0.122	0.161	0.491	3.377	1.445	0.246	0.453	0.101
25	0.084	0.136	0.071	0.163	0.119	0.161	0.503	3.016	1.411	0.242	0.276	0.100
26	0.081	0.109	0.069	0.152	0.119	0.156	0.473	2.724	1.349*	0.250	0.229	0.095
27	0.081	0.103	0.069	0.142	0.118	0.151	0.447	2.641	1.190	0.234	0.213	0.094
28	0.090	0.096	0.069	0.135	0.190	0.148	0.408	2.980	1.098	0.230	0.240	0.092
29	0.084	0.093	0.067	0.133		0.148	0.396	3.875	1.040	0.261	0.205	0.091
30	0.083	0.093	0.067	0.128		0.149	0.399	5.244	0.982	0.237	0.190	0.089
31	0.085		0.066	0.121		0.146		6.505		0.249	0.205	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	2.434	3.223	2.341	4.812	3.451	5.554	8.802	89.430	108.146	13.778	6.862	3.927
TOTAL FLOW (cms days)	0.069	0.091	0.066	0.136	0.098	0.157	0.249	2.533	3.063	0.390	0.194	0.111
TOTAL DEPTH (in)	0.166	0.220	0.160	0.329	0.236	0.380	0.602	6.117	7.397	0.942	0.469	0.269
TOTAL DEPTH (cm)	0.423	0.560	0.407	0.836	0.600	0.965	1.529	15.536	18.788	2.394	1.192	0.682

ANNUAL SUMMARY:
Sum of Mean Daily Flow 252.761 cfs = 7.158 cms
Total Depth 17.288 in = 43.911 cm
Maximum Instantaneous Flow 8.430 cfs = 0.239 cms on June 3 at 4.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 204
WATERSHED AREA: 348 ACRES (140 HECTARES)

WATER YEAR 1976
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.087	0.408	1.215	1.220*	0.552	0.395	0.454	2.631	1.651	0.712	0.300	0.191
2	0.084	0.465	1.409	0.526*	0.551	0.392	0.447	3.608	1.510	0.676	0.301	0.181
3	0.080	0.596	1.339	0.526*	0.548	0.436	0.479	4.702	1.411	0.643	0.299	0.174
4	0.183	0.697	1.351	0.526*	0.553	0.433	0.575	6.804	1.314	0.612	0.284	0.166*
5	0.109	0.770	1.261	0.526*	0.560	0.433	0.774	6.913	1.224	0.584	0.266	0.161*
6	0.129	0.746	1.170	0.526*	0.566	0.431	0.940	6.219	1.170	0.556	0.228	0.301*
7	0.239	0.665	1.434	0.526*	0.570	0.431	1.151	6.427	1.129	0.544	0.879	0.202*
8	0.155	0.578	1.727	0.526*	0.572	0.431	1.641	7.505	1.094	0.508	0.432	0.184*
9	0.133	0.507	1.860	0.525*	0.574	0.431	2.249	8.769	1.021	0.487	0.332	0.172*
10	0.123	0.461	1.771	0.524*	0.579	0.424	2.598	9.782	1.036	0.469	0.288	0.162
11	0.191	0.419	1.585	0.523*	0.583	0.413	2.972	10.015	0.936	0.452	0.262	0.182
12	0.226	0.379	1.406	0.524	0.600	0.407	3.417	7.931	0.952	0.690	0.250	0.192
13	0.175	0.369	1.239	0.524*	0.727	0.403	3.518	7.471	0.960	0.485	0.246	0.165
14	0.164	0.369	1.130	0.545*	0.697	0.402	3.378	7.986	0.938	0.446	0.245	0.156
15	0.180	0.410	1.001	0.981*	0.626	0.401	3.077	6.561	0.869	0.423	0.359	0.152
16	0.156	0.369	0.889	0.796*	0.535	0.384	2.705	5.832	1.078	0.399	0.332	0.164
17	0.146	0.342	0.831	0.718	0.484	0.384	2.373	5.480	1.137	0.394	0.279	0.188
18	0.174	0.319	0.820	0.725	0.477	0.397	2.152	4.780	1.035	0.435	0.354	0.166
19	0.162	0.306	0.813	0.723	0.472	0.395	1.930	4.299	0.975	0.394	0.304	0.157
20	0.240	0.306	0.819	0.721	0.443	0.391	1.897	3.947	1.022	0.399	0.281	0.148
21	0.719*	0.305	0.818	0.720	0.441	0.384	1.783	3.545	1.192	0.411	0.266	0.144
22	0.505*	0.304	0.818	0.714	0.441	0.391	1.728	3.371	1.160	0.358	0.286	0.143
23	0.380*	0.302	0.684	0.695	0.426	0.415	1.687	3.305	1.125	0.336	0.302	0.172
24	0.316*	0.409	0.631	0.674	0.409	0.406	1.768	3.163	1.069	0.413	0.260	0.155
25	0.299	0.305	0.551	0.655	0.397	0.399	1.840	3.225	1.016	0.349	0.384*	0.146
26	0.335	0.299	0.614	0.639	0.383	0.395	1.822	2.715	0.955	0.317	0.382*	0.139
27	0.292	0.287	0.539	0.622	0.399	0.395	1.762	2.589	0.892	0.294	0.287*	0.134
28	0.282	0.285	0.513	0.600	0.407	0.396	1.704	2.375	0.831	0.280	0.238*	0.130
29	0.299	0.285	0.559	0.589	0.401	0.394	1.776	2.040	0.787	0.272	0.220	0.125
30	0.391	0.285	0.530	0.570		0.416	2.038	1.900	0.745	0.264	0.210	0.122
31	0.444		1.287*	0.556		0.445		1.829		0.262	0.201	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	7.398	12.546	32.610	19.765	14.973	12.649	56.635	157.719	32.234	13.859	9.557	4.972
TOTAL FLOW (cms days)	0.210	0.355	0.924	0.560	0.424	0.358	1.604	4.467	0.913	0.392	0.271	0.141
TOTAL DEPTH (in)	0.506	0.858	2.230	1.352	1.024	0.865	3.874	10.787	2.205	0.948	0.654	0.340
TOTAL DEPTH (cm)	1.285	2.179	5.665	3.434	2.601	2.198	9.839	27.400	5.600	2.408	1.660	0.864

ANNUAL SUMMARY:
Sum of Mean Daily Flow 374.918 cfs = 10.618 cms
Total Depth 25.643 in = 65.132 cm
Maximum Instantaneous Flow 12.300 cfs = 0.348 cms on June 10 at 20.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 204
WATERSHED AREA: 348 ACRES (140 HECTARES)

WATER YEAR 1977
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.120	0.257	0.116	0.107	0.118*	0.161*	0.161*	1.447	0.407	0.143	0.070	0.094
2	0.224	0.181	0.117	0.107	0.118*	0.157*	0.163*	1.370	0.387	0.169	0.067	0.072
3	0.211	0.165	0.116	0.104	0.118*	0.150*	0.164*	1.105	0.364	0.150	0.065	0.065
4	0.160	0.155	0.113	0.100	0.118*	0.147*	0.198*	0.916	0.347	0.162	0.063	0.059
5	0.146	0.149	0.104	0.100	0.118*	0.145*	0.263*	0.789	0.333	0.155	0.061	0.056
6	0.147	0.144	0.099	0.100	0.118*	0.146*	0.339*	0.705	0.319	0.150	0.059	0.055
7	0.143	0.139	0.118	0.101	0.118*	0.148*	0.537	0.694	0.308	0.136	0.057	0.051
8	0.137	0.137	0.135	0.101	0.116*	0.148*	0.831	0.681	0.398	0.123	0.055	0.047
9	0.133	0.137	0.132	0.101	0.113*	0.149*	0.885	0.629	0.325	0.118	0.053	0.047
10	0.155	0.136	0.127	0.101	0.115*	0.146*	0.769	0.618	0.295	0.112	0.052	0.044
11	0.223	0.133	0.124	0.101	0.120*	0.139*	0.721	0.571	0.308	0.107	0.051	0.042
12	0.156	0.128	0.123	0.107*	0.128*	0.140*	0.737	0.517	0.313	0.103	0.049	0.041
13	0.146	0.122	0.123	0.113*	0.160*	0.140*	0.774	0.476	0.323	0.100	0.048	0.040
14	0.138	0.119	0.118	0.113*	0.144*	0.139*	0.760	0.448	0.308	0.097	0.047	0.039
15	0.133	0.128	0.114	0.115*	0.140*	0.136*	0.750	0.435	0.277	0.093	0.046	0.073
16	0.131	0.155	0.114	0.125*	0.140*	0.136*	0.783	0.454	0.260	0.090	0.044	0.122
17	0.129	0.156	0.116	0.155*	0.142*	0.135*	0.737	0.546	0.236	0.087	0.043	0.141
18	0.127	0.206	0.114	0.225*	0.150*	0.134*	0.710	0.565	0.228	0.166	0.042	0.071
19	0.125	0.152	0.108	0.191*	0.160*	0.142*	0.680	0.661	0.216	0.130	0.041	0.065
20	0.124	0.145	0.103	0.154*	0.169*	0.147*	0.659	0.675	0.216	0.107	0.040	0.168
21	0.123	0.140	0.103	0.147*	0.189*	0.145*	0.695	0.682	0.211	0.098	0.040	0.157
22	0.120	0.141	0.103	0.144*	0.175*	0.152*	0.827	0.658	0.202	0.093	0.059	0.101
23	0.115	0.140	0.104	0.141*	0.166*	0.165*	1.176	0.638	0.193	0.086	0.044	0.083
24	0.116	0.152	0.104	0.138*	0.158*	0.163*	1.760	0.632	0.183	0.149	0.088	0.087
25	0.190	0.182	0.105	0.136*	0.151*	0.158*	2.329	0.578	0.177	0.138	0.134	0.106
26	0.168	0.133*	0.116	0.135*	0.155*	0.160*	2.386	0.551	0.166	0.141	0.227	0.097
27	0.146	0.127*	0.121	0.134*	0.150*	0.161*	1.903	0.532	0.155	0.097	0.183	0.081
28	0.140	0.125*	0.114	0.132*	0.153*	0.156*	1.641	0.519	0.149	0.086	0.116	0.116
29	0.132	0.123*	0.113	0.130*		0.154*	1.526	0.484	0.144	0.078	0.149	0.163
30	0.127	0.120	0.112	0.128*		0.157*	1.460	0.456	0.139	0.075	0.321	0.163
31	0.126		0.107	0.122*		0.159*		0.440		0.074	0.155	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	4.509	4.421	3.536	3.910	3.917	4.615	27.324	20.470	7.885	3.614	2.569	2.544
TOTAL FLOW (cms days)	0.128	0.125	0.100	0.111	0.111	0.131	0.774	0.580	0.223	0.102	0.073	0.072
TOTAL DEPTH (in)	0.308	0.302	0.242	0.267	0.268	0.316	1.869	1.400	0.539	0.247	0.176	0.174
TOTAL DEPTH (cm)	0.783	0.768	0.614	0.679	0.681	0.802	4.747	3.556	1.370	0.628	0.446	0.442

ANNUAL SUMMARY:
Sum of Mean Daily Flow 89.313 cfs = 2.529 cms
Total Depth 6.109 in = 15.516 cm
Maximum Instantaneous Flow 2.530 cfs = 0.072 cms on April 25 at 18.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 204
WATERSHED AREA: 348 ACRES (140 HECTARES)

WATER YEAR 1978
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.132	0.166*	0.442*	0.324*	0.227	0.423	5.773	2.642	1.483	0.451	0.177	0.115
2	0.104	0.276*	2.747*	0.322*	0.229	0.424	5.319	2.706	1.394	0.449	0.169	0.109
3	0.090	0.181*	2.027*	0.320*	0.239	0.426	4.103	2.761	1.300	0.444	0.163	0.103
4	0.082	0.174*	1.365*	0.318*	0.237	0.416	3.287	2.625	1.211	0.706	0.157	0.096
5	0.084	0.193	1.020*	0.316*	0.240	0.427	2.792	2.304	1.137	0.582	0.150	0.102
6	0.092	0.191	0.853*	0.315*	0.264	0.421	2.542	2.069	1.067	0.527	0.145	0.118
7	0.222	0.179	0.747*	0.312*	0.287	0.403	2.334	1.929	0.993	0.664	0.140	0.189
8	0.180	0.167	0.631*	0.324*	0.284	0.418	2.129	1.879	0.942	0.619	0.134	0.157
9	0.228	0.168*	0.561*	0.344*	0.282	0.512	1.991	1.973	0.916	0.562	0.128	0.120
10	0.183	0.171*	0.518*	0.311*	0.283	0.515	1.979	2.340	0.993	0.532	0.124	0.113
11	0.159	0.174*	0.532*	0.281*	0.286	0.528	2.263	2.607	0.910	0.489	0.120	0.152
12	0.148	0.176*	0.503*	0.260	0.288	0.545	2.209	2.570*	0.831	0.448	0.120	0.262
13	0.130	0.187*	0.615*	0.256	0.293	0.544	2.108	2.570*	0.776	0.415	0.224	0.166
14	0.117	0.215*	0.861*	0.255	0.287	0.542	1.976	2.570*	0.732	0.385	0.170	0.148
15	0.107	0.301	1.079*	0.255	0.280	0.516	1.930	2.481*	0.702	0.386	0.216	0.136
16	0.100	0.233	1.148*	0.256	0.278	0.508	1.958	2.239*	0.658	0.369	0.265	0.126
17	0.094	0.203	1.082*	0.256	0.269	0.541	1.871	2.069	0.621	0.353	0.239	0.123
18	0.090	0.182	0.932*	0.257	0.266	0.612	1.792	1.928	0.634	0.335	0.184	0.135
19	0.083	0.162*	0.789*	0.258	0.266	0.722	1.797	1.852	0.587	0.312	0.160	0.142
20	0.082	0.150*	0.664*	0.256	0.280	0.912	1.870	1.812	0.546	0.296	0.151	0.127
21	0.080	0.147*	0.604*	0.255	0.284	1.169	1.835	1.778	0.512	0.282	0.142	0.118
22	0.080	0.144*	0.586*	0.255	0.285	1.506	1.746	1.816	0.498	0.268	0.353	0.114
23	0.078*	0.146*	0.537*	0.254	0.295	1.895	1.634	1.700	0.476	0.258	0.196	0.110
24	0.076*	0.151*	0.502*	0.250	0.337	2.116	1.551	1.778	0.554	0.244	0.165	0.104
25	0.258*	0.482*	0.470*	0.245	0.363	2.075	1.714	1.806	0.683	0.229	0.151	0.102
26	0.236*	0.510*	0.438*	0.243	0.395	2.066	2.144	1.806	0.518	0.218	0.141	0.097
27	0.169*	0.352*	0.408*	0.247	0.411	2.406	2.546	1.832	0.467	0.210	0.132	0.093
28	0.159*	0.321*	0.378*	0.241	0.418	3.200	2.607	1.847	0.438	0.262	0.125	0.103
29	0.152*	0.456*	0.386*	0.236		4.020	2.582	1.802	0.569	0.223	0.120	0.101
30	0.169*	0.377*	0.378*	0.236		4.849	2.579	1.667	0.488	0.200	0.116	0.093
31	0.162*		0.354*	0.234		5.515		1.565		0.187	0.117	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	4.127	6.931	24.155	8.492	8.150	41.171	72.959	65.323	23.639	11.903	5.092	3.771
TOTAL FLOW (cms days)	0.117	0.196	0.684	0.240	0.231	1.166	2.066	1.850	0.669	0.337	0.144	0.107
TOTAL DEPTH (in)	0.282	0.474	1.652	0.581	0.557	2.816	4.990	4.468	1.617	0.814	0.348	0.258
TOTAL DEPTH (cm)	0.717	1.204	4.196	1.475	1.416	7.152	12.675	11.348	4.107	2.068	0.885	0.655

ANNUAL SUMMARY:
Sum of Mean Daily Flow 275.712 cfs = 7.808 cms
Total Depth 18.857 in = 47.898 cm
Maximum Instantaneous Flow 5.840 cfs = 0.165 cms on April 1 at 6.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 204
WATERSHED AREA: 348 ACRES (140 HECTARES)

WATER YEAR 1979
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.096	0.090	0.086	0.112	0.085	0.110*	0.463	3.424	0.791	0.266	0.073	0.086
2	0.091	0.091	0.090	0.112	0.085	0.099*	0.431	3.509	0.735	0.250	0.066	0.071
3	0.089	0.089	0.093	0.112	0.085	0.089*	0.398	3.548	0.684	0.228	0.063	0.063
4	0.094	0.095	0.101	0.111	0.085	0.086*	0.377	3.949	0.638	0.221	0.066	0.062
5	0.102	0.087	0.108	0.111	0.085	0.128*	0.409	4.930	0.612	0.214	0.063	0.058
6	0.101	0.086	0.116	0.111	0.084	0.357*	0.462	4.479	0.635	0.201	0.063	0.056
7	0.100	0.086	0.123	0.110	0.084	0.441*	0.597	3.617	0.588	0.193	0.060	0.052
8	0.099	0.407	0.131	0.108	0.084*	0.367*	0.638	3.050	0.544	0.185	0.059	0.050
9	0.097	0.156	0.132	0.106	0.084*	0.354	0.686	2.658	0.508	0.176	0.057	0.050
10	0.096	0.081	0.132	0.105	0.091*	0.337	0.676	2.376	0.476	0.169	0.054	0.074
11	0.094	0.068	0.132	0.103	0.110*	0.326	0.644	2.280	0.449	0.164	0.052	0.054
12	0.091	0.067	0.132	0.102	0.166*	0.327	0.609	2.267	0.423	0.161	0.053	0.049
13	0.092	0.069	0.132	0.101	0.340*	0.327	0.586	2.414	0.403	0.156	0.058	0.045
14	0.092	0.069	0.132	0.100	0.200*	0.327	0.558	2.549	0.386	0.150	0.060	0.044
15	0.091	0.068	0.132	0.099	0.152*	0.337	0.553	2.542	0.372	0.144	0.112	0.042
16	0.093	0.067	0.131	0.097	0.140*	0.366	0.593	2.539	0.361	0.137	0.075	0.040
17	0.093	0.068	0.131	0.096	0.131*	0.364	0.836	2.537	0.376	0.128	0.063	0.038
18	0.092	0.068	0.129	0.094	0.127*	0.349	0.933	2.519	0.427	0.121	0.093	0.036
19	0.090	0.069	0.127	0.093	0.126*	0.333	0.885	2.409	0.388	0.114	0.103	0.035
20	0.089	0.070	0.125	0.093	0.121*	0.332	0.821	2.215	0.360	0.109	0.077	0.034
21	0.088	0.070	0.123	0.093	0.121*	0.331	0.766	2.093	0.543	0.107	0.083	0.033
22	0.088	0.072	0.122	0.092	0.119*	0.334	0.808	1.949	0.393	0.126	0.070	0.033
23	0.088	0.073	0.121	0.092	0.118*	0.346	0.918	1.822	0.346	0.111	0.182	0.033
24	0.088	0.075	0.120	0.091	0.117*	0.384	1.079	1.744	0.321	0.101	0.121	0.032
25	0.087	0.075	0.119	0.090	0.116*	0.440	1.245	1.486	0.300	0.097	0.078	0.032
26	0.086	0.076	0.117	0.089	0.115*	0.438	1.437	1.330	0.281	0.093	0.081	0.036
27	0.085	0.077	0.115	0.089	0.116*	0.449	1.809	1.200	0.269	0.089	0.075	0.035
28	0.084	0.078	0.114	0.089	0.114*	0.569	2.352	1.112	0.254	0.094	0.066	0.032
29	0.087	0.079	0.112	0.088		0.600	2.967	1.003	0.243	0.092	0.073	0.031
30	0.089	0.081	0.112	0.087		0.558	3.338	0.927	0.250	0.082	0.154	0.031
31	0.086		0.112	0.086		0.513		0.861		0.076	0.211	

MONTHLY SUMMARY:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	2.836	2.707	3.698	3.063	3.400	10.717	28.872	75.333	13.355	4.554	2.558	1.366
TOTAL FLOW (cms days)	0.080	0.077	0.105	0.087	0.096	0.304	0.818	2.133	0.378	0.129	0.072	0.039
TOTAL DEPTH (in)	0.194	0.185	0.253	0.209	0.233	0.733	1.975	5.152	0.913	0.311	0.175	0.093
TOTAL DEPTH (cm)	0.493	0.470	0.643	0.532	0.591	1.862	5.016	13.087	2.320	0.791	0.444	0.237

ANNUAL SUMMARY:

Sum of Mean Daily Flow 152.458 cfs = 4.318 cms
Total Depth 10.427 in = 26.486 cm
Maximum Instantaneous Flow 5.030 cfs = 0.142 cms on May 5 at 17.00 hours

*** Indicates some data were estimated during this day.**

HORSE CREEK STUDY AREA
WATERSHED: 204
WATERSHED AREA: 348 ACRES (140 HECTARES)

WATER YEAR 1980
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.030	0.099	0.114*	0.113*	0.085*	0.313	0.195	1.755	1.547	0.642	0.235	0.119
2	0.029	0.093	0.114*	0.112*	0.085*	0.304	0.191	1.975	1.661	0.916	0.223	0.201
3	0.027	0.098	0.114*	0.112*	0.085*	0.299	0.184	2.651	1.631	0.979	0.217	0.135
4	0.027	0.114	0.164*	0.107*	0.084*	0.334	0.183	2.632	1.621	0.938	0.212	0.112
5	0.026	0.135	0.119*	0.099*	0.085*	0.334	0.200	2.273	1.588	0.910	0.201	0.101
6	0.026	0.121	0.117*	0.091*	0.085*	0.319	0.217	1.941	1.586	0.868	0.191	0.097
7	0.026	0.108	0.165*	0.086*	0.085*	0.313	0.207	1.654	1.476	0.797	0.183	0.095
8	0.026	0.103	0.149*	0.086*	0.085*	0.301	0.203	1.414	1.370	0.745	0.175	0.092
9	0.026	0.097	0.145*	0.086*	0.085*	0.288	0.224	1.203	1.281	0.861	0.167	0.088
10	0.026	0.092	0.184*	0.085*	0.085*	0.296	0.239	1.076	1.261	0.731	0.161	0.137
11	0.026	0.093	0.116*	0.085*	0.086*	0.298	0.263	0.954	1.261	0.659	0.156	0.225
12	0.025	0.086	0.115*	0.085*	0.085*	0.280	0.289	0.858	1.286	0.613	0.149	0.116
13	0.025	0.084	0.114*	0.085*	0.086*	0.273	0.401	0.792	1.255	0.578	0.145	0.238
14	0.025	0.084	0.115*	0.085*	0.086*	0.269	0.564	0.716	1.303	0.673	0.137	0.174
15	0.086	0.083	0.115*	0.085*	0.086*	0.256	0.770	0.798	1.318	0.576	0.133	0.126
16	0.054	0.085	0.124*	0.085*	0.086*	0.245	0.880	0.727	1.254	0.528	0.121	0.111
17	0.088	0.168	0.219*	0.085*	0.086*	0.241	1.175	0.670	1.194	0.486	0.120	0.100
18	0.090	0.128	0.205*	0.086*	0.107*	0.240	1.700	0.625	1.116	0.461	0.294	0.199
19	0.209	0.113	0.162*	0.086*	0.155*	0.234	2.211	0.581	1.028	0.430	0.156	0.172
20	0.090	0.105	0.145*	0.085*	0.170*	0.228	2.558	0.544	0.955	0.402	0.145	0.455
21	0.090	0.107	0.134*	0.085*	0.156*	0.228	2.629	0.548	0.885	0.378	0.136	0.370
22	0.094	0.107	0.123*	0.085*	0.156	0.222	2.624	0.563	0.864	0.356	0.127	0.221
23	0.105	0.106	0.113*	0.085*	0.156	0.217	2.617	0.589	0.796	0.336	0.119	0.191
24	0.086	0.106	0.113*	0.085*	0.153	0.209	2.619	0.646	0.736	0.316	0.113	0.167
25	0.081	0.106	0.113*	0.085*	0.153	0.202	2.619	0.992	0.682	0.299	0.108	0.152
26	0.090	0.107	0.113*	0.085*	0.161	0.202	2.608	1.438	0.723	0.281	0.104	0.141
27	0.068	0.109	0.113*	0.085*	0.214	0.203	2.602	1.709	0.702	0.267	0.106	0.134
28	0.066	0.111	0.113*	0.085*	0.314	0.201	2.609	1.721	0.611	0.257	0.104	0.125
29	0.076	0.112	0.113*	0.085*	0.331	0.201	2.510	1.644	0.566	0.246	0.100	0.119
30	0.083	0.113	0.113*	0.085*		0.201	1.967	1.584	0.534	0.254	0.096	0.107
31	0.102		0.113*	0.085*		0.196		1.458		0.239	0.130	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	1.925	3.172	4.086	2.766	3.676	7.948	38.257	38.729	34.089	17.022	4.761	4.817
TOTAL FLOW (cms days)	0.055	0.090	0.116	0.078	0.104	0.225	1.083	1.097	0.965	0.482	0.135	0.136
TOTAL DEPTH (in)	0.132	0.217	0.279	0.189	0.251	0.544	2.617	2.649	2.332	1.164	0.326	0.329
TOTAL DEPTH (cm)	0.334	0.551	0.710	0.480	0.639	1.381	6.646	6.728	5.922	2.957	0.827	0.837

ANNUAL SUMMARY:
Sum of Mean Daily Flow 161.248 cfs = 4.567 cms
Total Depth 11.029 in = 28.013 cm
Maximum Instantaneous Flow 2.510 cfs = 0.071 cms on May 2 at 16.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 204
WATERSHED AREA: 348 ACRES (140 HECTARES)

WATER YEAR 1981
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.106	0.079	0.115	0.922	0.235	0.594	0.883	0.979	0.804	0.973	0.332	0.184
2	0.103	0.099	0.137	0.817	0.234	0.579	0.835	0.922	0.760	0.915	0.271	0.155
3	0.101	0.088	0.195	0.731	0.207	0.563	0.831	0.860	0.723	0.858	0.217	0.131
4	0.099	0.086	0.202	0.657	0.205	0.555	0.767	0.830	0.736	0.797	0.188	0.116
5	0.096	0.082	0.159	0.590	0.215	0.531	0.752	0.807	0.714	0.750	0.195	0.108
6	0.093	0.174	0.148	0.533	0.212	0.514	0.710	0.758	1.039	0.864	0.186	0.105
7	0.088	0.372	0.134	0.488	0.215	0.493	0.659	0.720	0.947	0.901	0.177	0.100
8	0.088	0.202	0.112	0.438	0.220	0.484	0.641	0.686	1.846	0.739	0.169	0.099
9	0.087	0.203	0.112	0.415	0.215	0.475	0.628	0.643	2.340	0.708	0.162	0.097
10	0.085	0.187	0.113	0.389	0.181	0.470	0.601	0.641	2.361	1.339	0.156	0.094
11	0.085	0.158	0.117	0.368	0.192	0.472	0.588	0.732	2.149	1.163	0.162	0.095
12	0.097	0.140	0.124	0.352	0.233	0.486	0.568	0.671	2.637	1.212	0.147	0.092
13	0.098	0.118	0.126	0.331	0.283	0.513	0.536	0.624	2.644	1.147	0.143	0.087
14	0.094	0.098	0.126	0.309	0.430	0.535	0.542	0.610	2.643	1.073	0.139	0.086
15	0.094	0.096	0.154	0.292	0.326	0.565	0.636	0.691	2.656	0.994	0.135	0.083
16	0.094	0.087	0.171	0.280	0.789	0.622	0.705	0.642	2.683	0.916	0.126	0.080
17	0.092	0.099	0.184	0.271	0.720	0.621	0.787	0.627	2.640	0.915	0.120	0.076
18	0.092	0.104	0.166	0.265	0.708	0.616	0.961	0.601	2.623	0.979	0.118	0.073
19	0.091	0.106	0.153	0.257	0.762	0.615	1.190	0.584	2.624	0.916	0.149	0.124
20	0.087	0.106	0.151	0.248	0.751	0.621	1.312	0.580	2.627	0.895	0.141	0.087
21	0.085	0.128	0.208	0.244	0.741	0.598	1.337	0.997	2.622	0.833	0.120	0.090
22	0.085	0.149	0.513	0.245	0.703	0.605	1.344	0.987	2.636	0.743*	0.111	0.079
23	0.083	0.100	0.387	0.403	0.687	0.606	1.408	1.037	2.472	0.594*	0.105	0.077
24	0.083	0.098	0.411	0.361	0.669	0.598	1.479	1.030	2.099	0.447*	0.099	0.071
25	0.085	0.092	1.345	0.292	0.661	0.741	1.349	1.113	1.824	0.527	0.095	0.148
26	0.104	0.096	2.475	0.268	0.640	0.805	1.240	1.059	1.604	0.487	0.093	0.098
27	0.091	0.114	2.422	0.269	0.625	0.860	1.184	1.008	1.429	0.428	0.091	0.259
28	0.084	0.144	1.950	0.277	0.608	0.877	1.154	0.951	1.283	0.406	0.089	0.189
29	0.083	0.127	1.421	0.267		0.932	1.104	0.894	1.161	0.385	0.087	0.112
30	0.082	0.120	1.217	0.258		0.903	1.040	0.941	1.065	0.375	0.303	0.096
31	0.081		1.034	0.247		0.917		0.906		0.372	0.188	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	2.817	3.850	16.282	12.086	12.664	19.365	27.768	25.129	56.390	24.650	4.812	3.289
TOTAL FLOW (cms days)	0.080	0.109	0.461	0.342	0.359	0.548	0.786	0.712	1.597	0.698	0.136	0.093
TOTAL DEPTH (in)	0.193	0.263	1.114	0.827	0.866	1.324	1.899	1.719	3.857	1.686	0.329	0.225
TOTAL DEPTH (cm)	0.489	0.669	2.828	2.100	2.200	3.364	4.824	4.366	9.796	4.282	0.836	0.571

ANNUAL SUMMARY:
Sum of Mean Daily Flow 209.102 cfs = 5.922 cms
Total Depth 14.302 in = 36.326 cm
Maximum Instantaneous Flow 3.050 cfs = 0.086 cms on June 12 at 15.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 204
WATERSHED AREA: 348 ACRES (140 HECTARES)

WATER YEAR 1982
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.092	0.100	0.154	0.152	0.194	0.466	0.485	2.247*	2.751*	0.989	0.267	0.128
2	0.091	0.093	0.152	0.152	0.194	0.466	0.485	2.710*	2.985*	0.867	0.314	0.124
3	0.092	0.102	0.154	0.152	0.193	0.465	0.484	3.490*	3.328*	0.853	0.279	0.121
4	0.089	0.114	0.156	0.152	0.192	0.462	0.479	3.274*	3.232*	0.820	0.246	0.117
5	0.087	0.112	0.180	0.152	0.188	0.451	0.467	2.708*	3.006*	0.814	0.230	0.116
6	0.085	0.109	0.323	0.153	0.187	0.446	0.460	2.325*	2.784*	0.753	0.219	0.112
7	0.101	0.108	0.254	0.153	0.187	0.444	0.450	2.327*	2.814*	0.770	0.208	0.107
8	0.095	0.107	0.214	0.152	0.184	0.438	0.438	2.434*	2.600*	0.751	0.210	0.105
9	0.178	0.105	0.231	0.152	0.182	0.458	0.430	2.484*	2.614*	0.736	0.208	0.108
10	0.237	0.104	0.284	0.152	0.179	0.497	0.426	2.427*	2.484*	0.698	0.198	0.359
11	0.249	0.104	0.231	0.153	0.178	0.552	0.544	2.410*	2.478*	0.660	0.205	0.180
12	0.181	0.163	0.210	0.152	0.178	0.571	0.762	2.494*	2.455*	0.620	0.206	0.241
13	0.138	0.163	0.199	0.154	0.178	0.576	0.860	2.795*	2.327*	0.645	0.192	0.172
14	0.122	0.147	0.194	0.161	0.389	0.578	0.892	3.481*	2.192*	0.657	0.187	0.151
15	0.110	0.131	0.188	0.163	0.438	0.592	0.899	4.180*	1.953*	0.578	0.180	0.149
16	0.103	0.131	0.184	0.165	0.576	0.587	0.900	4.271*	1.744	0.590	0.172	0.143
17	0.100	0.205	0.172	0.172	0.571	0.582	0.891	4.263*	1.532	0.540	0.165	0.135
18	0.095	0.183	0.160	0.169	0.569	0.573	0.849	4.243*	1.371	0.509	0.160	0.129
19	0.091	0.150	0.427	0.169	0.578	0.549	0.785	4.185*	1.243	0.486	0.158	0.124
20	0.087	0.147	0.244	0.166	0.665	0.528	0.735	3.628*	1.143	0.464	0.196	0.137
21	0.084	0.197	0.193	0.159	0.809	0.508	0.701	3.598*	1.055	0.440	0.189	0.128
22	0.084	0.227	0.172	0.159	0.829	0.491	0.751*	3.977*	0.995	0.420	0.156	0.125
23	0.084	0.190	0.158	0.179	0.757	0.480	0.926*	4.221*	0.951	0.398	0.144	0.120
24	0.084	0.180	0.153	0.259	0.668	0.473	1.263*	4.341*	0.889	0.380	0.137	0.118
25	0.085	0.177	0.153	0.206	0.602	0.466	1.606*	4.271*	0.843	0.367	0.133	0.120
26	0.151	0.170	0.153	0.201	0.554	0.469	1.715*	4.302*	0.794	0.354	0.129	0.222
27	0.122	0.160	0.152	0.200	0.515	0.474	1.788*	3.844*	0.763	0.331	0.124	0.264
28	0.098	0.155	0.152	0.196	0.486	0.476	1.955*	3.350*	0.889	0.316	0.120	0.399
29	0.096	0.156	0.152	0.194		0.479	2.169*	3.016*	0.853	0.303	0.121	0.236
30	0.102	0.155	0.152	0.193		0.481	2.211*	2.760*	0.798	0.283	0.188	0.180
31	0.111		0.152	0.194		0.482		2.652*		0.289	0.142	
MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	3.524	4.343	6.050	5.287	11.417	15.560	27.803	102.709	55.862	17.679	5.783	4.866
TOTAL FLOW (cms days)	0.100	0.123	0.171	0.150	0.323	0.441	0.787	2.909	1.582	0.501	0.164	0.138
TOTAL DEPTH (in)	0.241	0.297	0.414	0.362	0.781	1.064	1.902	7.025	3.821	1.209	0.396	0.333
TOTAL DEPTH (cm)	0.612	0.755	1.051	0.918	1.983	2.703	4.830	17.843	9.705	3.071	1.005	0.845

ANNUAL SUMMARY:
Sum of Mean Daily Flow 260.882 cfs = 7.388 cms
Total Depth 17.843 in = 45.322 cm
Maximum Instantaneous Flow 4.640 cfs = 0.131 cms on May 24 at 15.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 204
WATERSHED AREA: 348 ACRES (140 HECTARES)

WATER YEAR 1983
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.178	0.222	0.154	0.122	0.206	0.592	0.481	0.943	0.423	0.357	0.121	0.148
2	0.171	0.199	0.149	0.121	0.270	0.634	0.488	0.922	0.414	0.352	0.116	0.132
3	0.338	0.191	0.158	0.122	0.188	0.697	0.464	0.852	0.395	0.303	0.107	0.091
4	0.237	0.195	0.318	0.132	0.185	0.777	0.449	0.791	0.369	0.247	0.102	0.084
5	0.220	0.205	0.208	0.332	0.176	0.853	0.438	0.901	0.350	0.223	0.098	0.081
6	0.195	0.230	0.200	0.317	0.178	0.920	0.436	0.870	0.333	0.211	0.094	0.074
7	0.281	0.195	0.184	0.449	0.182	0.968	0.434	0.772	0.316	0.204	0.097	0.081
8	0.282	0.183	0.175	0.410	0.183	0.901	0.427	0.771	0.308	0.194	0.103	0.093
9	0.245	0.187	0.165	0.352	0.184	0.968	0.415	0.735	0.300	0.206	0.255	0.092
10	0.221	0.184	0.161	0.325	0.190	1.135	0.404	0.736	0.338	0.258	0.174	0.218
11	0.213	0.177	0.160	0.303	0.192	1.315	0.387	0.690	0.320	0.197	0.196	0.228
12	0.199	0.156	0.159	0.288	0.209	1.372	0.378	0.666	0.385	0.180	0.132	0.132
13	0.189	0.165	0.159	0.270	0.213	1.375	0.363	0.653	0.323	0.171	0.116	0.118
14	0.182	0.158	0.159	0.257	0.204	1.301	0.359	0.636	0.287	0.392	0.135	0.112
15	0.177	0.156	0.155	0.240	0.203	1.180	0.361	0.703	0.309	0.232	0.126	0.105
16	0.173	0.164	0.175	0.230	0.216	1.049	0.380	0.708	0.273	0.209	0.111	0.101
17	0.179	0.187	0.189	0.226	0.248	0.948	0.450	0.734	0.328	0.192	0.100	0.100
18	0.188	0.196	0.166	0.220	0.555	0.851	0.549	0.823	0.367	0.180	0.086	0.135
19	0.184	0.193	0.164	0.217	0.511	0.747	0.669	0.832	0.303	0.171	0.082	0.147
20	0.190	0.180	0.162	0.211	0.454	0.677	0.818	0.811	0.275	0.216	0.083	0.120
21	0.200	0.171	0.163	0.206	0.432	0.634	0.968	0.783	0.254	0.179	0.088	0.116
22	0.199	0.161	0.166	0.203	0.436	0.598	1.106	0.737	0.238	0.163	0.116	0.109
23	0.185	0.151	0.162	0.201	0.452	0.574	1.312	0.692	0.227	0.158	0.109	0.103
24	0.183	0.142	0.154	0.199	0.493	0.530	1.689	0.649	0.219	0.177	0.101	0.098
25	0.187	0.139	0.145	0.195	0.557	0.516	1.526	0.613	0.208	0.168	0.090	0.097
26	0.241	0.138	0.151	0.202	0.612	0.494	1.285	0.576	0.199	0.155	0.083	0.095
27	0.242	0.138	0.149	0.233	0.619	0.476	1.121	0.555	0.228	0.145	0.080	0.096
28	0.216	0.157	0.143	0.234	0.610	0.454	1.016	0.521	0.225	0.139	0.075	0.095
29	0.260	0.166	0.140	0.223		0.442	0.981	0.489	0.248	0.132	0.071	0.094
30	0.249	0.162	0.133	0.220		0.520	0.963	0.462	0.230	0.125	0.068	0.109
31	0.215		0.127	0.215		0.489		0.439		0.121	0.073	

MONTHLY SUMMARY:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	6.616	5.244	5.150	7.472	9.157	24.985	21.113	22.064	8.991	6.357	3.389	3.404
TOTAL FLOW (cms days)	0.187	0.149	0.146	0.212	0.259	0.708	0.598	0.625	0.255	0.180	0.096	0.096
TOTAL DEPTH (in)	0.452	0.359	0.352	0.511	0.626	1.709	1.444	1.509	0.615	0.435	0.232	0.233
TOTAL DEPTH (cm)	1.149	0.911	0.895	1.298	1.591	4.341	3.668	3.833	1.562	1.104	0.589	0.591

ANNUAL SUMMARY:

Sum of Mean Daily Flow 123.943 cfs = 3.510 cms
Total Depth 8.477 in = 21.532 cm
Maximum Instantaneous Flow 1.910 cfs = 0.054 cms on March 7 at 19.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 204
WATERSHED AREA: 348 ACRES (140 HECTARES)

WATER YEAR 1984
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.097	0.102	0.123	0.107	0.289	0.231	0.558	1.220	4.356	0.788	0.396	0.157
2	0.097	0.143	0.123	0.126	0.273	0.242	0.547	1.375	3.707	0.745	0.386	0.123
3	0.097	0.122	0.123	0.628	0.268	0.231	0.536	1.394	3.313	0.708	0.373	0.112
4	0.097	0.205	0.123	0.601	0.262	0.224	0.550	1.415	3.243	0.679	0.363	0.105
5	0.096	0.139	0.123	0.491	0.257	0.222	0.640	1.426	3.105	0.644	0.360	0.100
6	0.094	0.246	0.123	0.482	0.253	0.221	0.735	1.364	2.983	0.613	0.364	0.156
7	0.092	0.181	0.122	0.443	0.249	0.221	0.745	1.322	3.262	0.586	0.353	0.121
8	0.092	0.152	0.123	0.414	0.246	0.225	0.817	1.390	3.185	0.558	0.341	0.170
9	0.161	0.137	0.123	0.369	0.244	0.242	0.842	2.254*	3.010	0.531	0.330	0.128
10	0.119	0.139	0.123	0.340	0.241	0.278	0.854	2.720*	2.817	0.512	0.322	0.113
11	0.107	0.208	0.123	0.318	0.236	0.350	0.830	2.753*	2.929	0.491	0.316	0.108
12	0.098	0.236	0.122	0.290	0.239	0.338	0.802	3.337*	2.691	0.467	0.309	0.106
13	0.099	0.217	0.122	0.279	0.382	0.353	0.777	4.293*	2.526	0.447	0.301	0.101
14	0.100	0.183	0.122	0.257	0.352	0.531	0.835	5.898*	2.366	0.431	0.290	0.097
15	0.099	0.190	0.123	0.238	0.315	0.543	1.215	5.469*	2.212	0.411	0.269	0.093
16	0.098	0.203	0.122	0.231	0.307	0.562	2.088	4.263*	2.034	0.390	0.252	0.090
17	0.131	0.215	0.122	0.221	0.295	0.565	2.417	3.580*	1.855	0.373	0.239	0.088
18	0.155	0.199	0.121	0.210	0.284	0.541	2.410	3.472*	1.715	0.371	0.225	0.083
19	0.115	0.180	0.118	0.199	0.276	0.589	2.410	3.988*	1.595	0.356	0.203	0.078
20	0.107	0.173	0.110	0.189	0.272	0.856	2.410	5.020*	1.528	0.341	0.184	0.303
21	0.102	0.156	0.104	0.186	0.270	1.016	2.412	4.623*	1.702	0.327	0.169	0.249
22	0.171	0.136	0.100	0.184	0.261	1.023	2.423	3.881*	1.434	0.314	0.156	0.169
23	0.203	0.139	0.098	0.178	0.248	0.963	2.410	4.639*	1.280	0.303	0.145	0.195
24	0.130	0.162	0.097	0.434	0.244	0.910	2.403	4.414*	1.193	0.282	0.132	0.169
25	0.118	0.167	0.099	0.542	0.245	0.829	2.299	3.760*	1.161	0.320	0.119	0.147
26	0.111	0.150	0.100	0.375	0.235	0.774	1.983	3.866*	1.057	0.401	0.110	0.141
27	0.106	0.150	0.098	0.351	0.230	0.710	1.726	4.067*	0.990	0.362	0.102	0.134
28	0.103	0.151	0.098	0.341	0.230	0.658	1.537	4.201*	0.928	0.562	0.096	0.126
29	0.103	0.132	0.099	0.326	0.228	0.619	1.374	4.835*	0.886	0.474	0.097	0.122
30	0.103	0.124	0.104	0.314		0.591	1.244	6.167*	0.835	0.442	0.132	0.117
31	0.102		0.106	0.301		0.570		5.443		0.410	0.209	
MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	3.502	5.036	3.538	9.963	7.729	16.228	42.827	107.847	65.896	14.638	7.641	3.996
TOTAL FLOW (cms days)	0.099	0.143	0.100	0.282	0.219	0.460	1.213	3.054	1.866	0.415	0.216	0.113
TOTAL DEPTH (in)	0.240	0.344	0.242	0.681	0.529	1.110	2.929	7.376	4.507	1.001	0.523	0.273
TOTAL DEPTH (cm)	0.608	0.875	0.615	1.731	1.343	2.819	7.440	18.736	11.448	2.543	1.327	0.694

ANNUAL SUMMARY:
Sum of Mean Daily Flow 288.839 cfs = 8.180 cms
Total Depth 19.755 in = 50.179 cm
Maximum Instantaneous Flow 7.120 cfs = 0.202 cms on May 30 at 14.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 206
WATERSHED AREA: 256 ACRES (103 HECTARES)

WATER YEAR 1975
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.125	0.147	0.129	0.120	0.172*	0.261*	0.185	0.327	5.395	0.757	0.266	0.252
2	0.123	0.138	0.130	0.120	0.171*	0.299*	0.186	0.364	5.835	0.723	0.249	0.241
3	0.123	0.133	0.135	0.120	0.168*	0.289*	0.186	0.455	5.759	0.672	0.241	0.228
4	0.124	0.129	0.143	0.118*	0.166*	0.278*	0.186	0.455	4.931	0.631	0.234	0.218
5	0.125	0.131	0.132	0.118*	0.166*	0.253*	0.186	0.454	4.708	0.598	0.227	0.211
6	0.128	0.137	0.126	0.118*	0.166*	0.230*	0.186	0.435	5.018	0.567	0.221	0.207
7	0.129	0.147	0.127	0.118*	0.166*	0.208*	0.186	0.518	4.701	0.540	0.269	0.203
8	0.127	0.148	0.125	0.118*	0.166*	0.192*	0.186	0.617	3.995	0.514	0.227	0.194
9	0.123	0.135	0.123	0.118*	0.166*	0.195*	0.186	0.769	3.467	0.489	0.215	0.189
10	0.122	0.136	0.122	0.118*	0.166*	0.191*	0.185	1.064	3.097	0.463	0.207	0.186
11	0.139	0.130	0.134	0.118*	0.166*	0.187*	0.186	1.620	2.950	0.437	0.203	0.183
12	0.129	0.149	0.128	0.118	0.166*	0.183*	0.206	1.987	2.877	0.423	0.200	0.181
13	0.124	0.159	0.127	0.119	0.174*	0.181	0.226	2.121	2.697	0.430	0.194	0.179
14	0.122	0.139	0.124	0.130	0.168*	0.177	0.235	2.848	2.308	0.433	0.190	0.175
15	0.121	0.135	0.121	0.152	0.166*	0.180	0.317	4.478	2.065	0.436	0.187	0.173
16	0.119	0.130	0.151	0.134	0.166*	0.167	0.329	4.775	1.826	0.405	0.188	0.245
17	0.117	0.134	0.143	0.488	0.166*	0.164	0.301	4.768	1.610	0.382	0.261	0.271
18	0.116	0.152	0.133	0.945	0.166*	0.166	0.294	4.504	1.478	0.363	0.308	0.206
19	0.116	0.145	0.128	0.353	0.166*	0.171	0.284	3.413	1.365	0.353	0.290	0.185
20	0.118	0.160	0.147	0.259	0.166*	0.165	0.292	2.763	1.344	0.340	0.291	0.174
21	0.163	0.169	0.181	0.222	0.166*	0.164	0.292	2.161	1.302	0.327	0.232	0.170
22	0.154	0.173	0.142	0.202	0.166*	0.164	0.313	1.886	1.195	0.308	0.239	0.167
23	0.142	0.147	0.133	0.195	0.166	0.161	0.360	2.084	1.097	0.295	0.591	0.164
24	0.135	0.163	0.128	0.229	0.166	0.159	0.367	2.588	1.031	0.286	0.447	0.161
25	0.127	0.168	0.128	0.193	0.166	0.158	0.393	2.301	1.014	0.278	0.310	0.160
26	0.124	0.148	0.126	0.181	0.166	0.158	0.372	1.917	0.960	0.273	0.270	0.160
27	0.123	0.142	0.128	0.175*	0.166*	0.158	0.361	1.797	0.899	0.267	0.257	0.160
28	0.128	0.138*	0.127	0.175*	0.256*	0.169	0.334	1.722	0.860	0.270	0.309	0.158
29	0.128	0.136*	0.124	0.175*		0.183	0.323	2.656	0.813	0.316	0.264	0.155
30	0.128*	0.132	0.123	0.175*		0.185	0.327	3.465	0.769	0.281	0.246	0.153
31	0.129*		0.121	0.173*		0.185		4.666		0.285	0.259	
MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	3.948	4.325	4.090	6.094	4.751	5.978	7.969	65.977	77.365	13.141	8.093	5.708
TOTAL FLOW (cms days)	0.112	0.122	0.116	0.173	0.135	0.169	0.226	1.868	2.191	0.372	0.229	0.162
TOTAL DEPTH (in)	0.367	0.402	0.380	0.567	0.442	0.556	0.741	6.134	7.193	1.222	0.752	0.531
TOTAL DEPTH (cm)	0.932	1.021	0.966	1.439	1.122	1.412	1.882	15.581	18.270	3.103	1.911	1.348

ANNUAL SUMMARY:
Sum of Mean Daily Flow 207.439 cfs = 5.875 cms
Total Depth 19.287 in = 48.988 cm
Maximum Instantaneous Flow 6.070 cfs = 0.172 cms on June 2 at 22.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 206
WATERSHED AREA: 256 ACRES (103 HECTARES)

WATER YEAR 1976
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.153	0.414	0.395	0.975*	0.566*	0.352	0.414*	1.887	1.129	0.593	0.278	0.249
2	0.151	0.485	0.894	0.500*	0.563*	0.352	0.406*	2.682	1.032	0.578	0.305	0.238
3	0.146	0.594	1.335	0.477*	0.558*	0.353	0.434*	3.448	0.971*	0.546	0.318	0.234
4	0.242	0.696	1.371	0.454*	0.553*	0.354	0.518*	4.611	0.933*	0.524	0.318	0.225
5	0.171	0.777	1.290	0.432*	0.549*	0.354	0.703*	4.545	0.905*	0.504	0.305	0.221
6	0.194	0.749	1.189	0.411*	0.544*	0.350	0.867*	4.001	0.878*	0.485	0.300	0.219
7	0.283	0.668	1.273	0.396*	0.542*	0.352	1.056*	4.198	0.850*	0.478	0.274	0.361
8	0.211	0.575	1.487	0.398*	0.538*	0.352	1.506*	4.998	0.827	0.453	0.338	0.259
9	0.188	0.506	1.730	0.351*	0.533*	0.352	2.096*	5.759	0.787	0.442	0.518	0.237
10	0.177	0.465	1.705	0.331*	0.529*	0.357	2.428*	6.419	0.800	0.428	0.349	0.231
11	0.252	0.419	1.521	0.313*	0.522*	0.362	2.762*	6.717	0.750	0.417	0.316	0.223
12	0.281	0.432	1.381	0.295*	0.520*	0.361	3.193*	5.413	0.708	0.431	0.295	0.236
13	0.236	0.371	1.226	0.278*	0.520	0.356	3.317*	5.199	0.767	0.793	0.276	0.252
14	0.222	0.373	1.099	0.271*	0.503	0.336	3.192*	5.762	0.745	0.431	0.282	0.228
15	0.240	0.411	0.994	0.576*	0.478	0.331	2.917*	4.698	0.695	0.404	0.280	0.215
16	0.214	0.372	0.892	0.572*	0.478	0.333	2.564*	4.160	0.776	0.386	0.322	0.206
17	0.201	0.338*	0.865	0.552*	0.474	0.341	2.210*	3.964	0.914	0.369	0.364	0.212
18	0.228	0.288*	0.861	0.587*	0.459	0.356*	1.872*	3.487	0.850	0.364	0.306	0.239
19	0.228	0.275*	0.858	0.604	0.457	0.355*	1.572*	3.200	0.799	0.399	0.336	0.222
20	0.288	0.276*	0.855	0.601	0.457	0.352*	1.418*	2.993	0.807	0.374	0.321	0.214
21	0.821	0.274*	0.852	0.601	0.457	0.346*	1.212*	2.727	0.794	0.366	0.292	0.202
22	0.549	0.272*	0.850	0.601	0.457	0.353*	1.146	2.630	0.927	0.378	0.287	0.196
23	0.433	0.270*	0.847	0.599	0.438	0.375*	1.122	2.626	0.879	0.343	0.292	0.196
24	0.370	0.402*	0.680	0.599	0.402	0.365*	1.184	2.478	0.847	0.324	0.341	0.229
25	0.352	0.392	0.582	0.595	0.370	0.363*	1.234	2.463	0.804	0.397	0.295	0.208
26	0.355	0.392	0.591	0.592	0.363	0.362*	1.259	1.958	0.781	0.347	0.294	0.200
27	0.317	0.392	0.573	0.589*	0.370	0.359*	1.242	1.822	0.738	0.320	0.421	0.194
28	0.312	0.392	0.553	0.585*	0.358	0.357*	1.217	1.692	0.692	0.304	0.313	0.191
29	0.347	0.392	0.550	0.580*	0.000	0.356*	1.252	1.398	0.653	0.292	0.293	0.186
30	0.426	0.392	0.557	0.576*		0.378*	1.428	1.300	0.626	0.283	0.275	0.183
31	0.420		0.946*	0.572*		0.404*		1.267		0.280	0.261	
MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	9.006	13.051	30.802	15.866	13.557	11.030	47.739	110.499	24.661	13.033	9.761	6.705
TOTAL FLOW (cms days)	0.255	0.370	0.872	0.449	0.384	0.312	1.352	3.129	0.698	0.369	0.276	0.190
TOTAL DEPTH (in)	0.837	1.213	2.864	1.475	1.260	1.026	4.439	10.274	2.293	1.212	0.908	0.623
TOTAL DEPTH (cm)	2.127	3.082	7.274	3.747	3.202	2.605	11.274	26.095	5.824	3.078	2.305	1.583

ANNUAL SUMMARY:
Sum of Mean Daily Flow 305.710 cfs = 8.658 cms
Total Depth 28.423 in = 72.196 cm
Maximum Instantaneous Flow 7.730 cfs = 0.219 cms on May 21 at 19.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 206
WATERSHED AREA: 256 ACRES (103 HECTARES)

WATER YEAR 1977
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.177	0.279	0.183	0.167	0.155	0.200	0.183	1.328	0.425	0.181	0.123	0.150
2	0.261	0.222	0.183	0.163	0.155	0.195	0.183	1.213	0.397	0.204	0.121	0.135
3	0.261	0.205	0.181	0.163	0.154	0.188	0.183	1.007	0.364	0.187	0.119	0.128
4	0.216	0.194	0.180	0.163	0.154	0.182	0.217	0.848	0.346	0.199	0.118	0.123
5	0.203	0.188	0.174	0.163	0.154	0.181	0.278	0.746	0.330	0.190	0.116	0.120
6	0.198	0.182	0.171	0.161	0.154	0.183	0.350	0.672	0.316	0.187	0.114	0.118
7	0.176	0.177	0.181	0.160	0.154	0.187	0.505	0.664	0.310	0.172	0.112	0.115
8	0.172	0.176	0.197	0.159	0.150	0.187	0.737	0.657	0.384	0.164	0.110	0.113
9	0.171	0.175	0.194	0.158	0.150	0.187	0.789	0.607	0.308	0.162	0.109	0.111
10	0.186	0.173	0.190	0.158	0.151	0.185	0.698	0.594	0.291	0.159	0.107	0.109
11	0.258	0.171	0.188	0.156	0.155	0.176	0.641	0.559	0.299	0.153	0.106	0.107
12	0.196	0.166	0.186	0.150	0.163	0.177	0.653	0.515	0.307	0.152	0.105	0.106
13	0.187	0.160	0.183	0.149	0.197	0.177	0.675	0.485	0.318	0.148	0.103	0.105
14	0.180	0.159	0.180	0.149	0.181	0.174	0.644	0.463	0.292	0.145	0.103	0.104
15	0.175	0.161	0.178	0.150	0.176	0.171	0.649	0.455	0.273	0.142	0.102	0.152
16	0.175	0.186	0.178	0.161	0.177	0.171	0.660	0.473	0.258	0.139	0.098	0.202
17	0.173	0.186	0.178	0.194	0.179	0.171	0.624	0.557	0.243	0.138	0.097	0.193
18	0.171	0.252	0.177	0.271	0.190	0.171	0.612	0.579	0.235	0.204	0.095	0.136
19	0.169	0.192	0.172	0.234	0.199	0.178	0.579	0.663	0.231	0.173	0.094	0.132
20	0.167	0.181	0.170	0.195	0.211	0.180	0.565	0.691	0.237	0.155	0.092	0.226
21	0.167	0.173	0.167	0.186	0.229	0.183	0.604	0.707	0.230	0.146	0.093	0.220
22	0.165	0.173	0.166	0.182	0.215	0.192	0.746	0.688	0.218	0.141	0.114	0.171
23	0.160	0.173	0.166	0.178	0.209	0.204	1.102	0.667	0.209	0.135	0.099	0.152
24	0.160	0.180	0.167	0.175	0.203	0.203	1.708	0.648	0.202	0.182	0.139	0.153
25	0.219	0.220	0.168	0.171	0.190	0.196	2.171	0.602	0.195	0.186	0.178	0.168
26	0.216	0.166*	0.178	0.169	0.196	0.195	2.078	0.532	0.192	0.187	0.257	0.163
27	0.190	0.146*	0.183	0.168	0.189	0.195	1.620	0.544	0.187	0.148	0.225	0.145
28	0.183	0.132	0.179	0.168	0.194	0.187	1.419	0.525	0.182	0.136	0.165	0.175
29	0.172	0.142	0.176	0.166		0.183	1.345	0.495	0.179	0.131	0.195	0.219
30	0.168	0.175	0.171	0.163		0.183	1.312	0.467	0.175	0.128	0.347	0.229
31	0.168		0.169	0.158		0.183		0.442		0.125	0.201	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	5.837	5.461	5.514	5.305	4.985	5.726	24.529	20.094	8.130	5.000	4.157	4.477
TOTAL FLOW (cms days)	0.165	0.155	0.156	0.150	0.141	0.162	0.695	0.569	0.230	0.142	0.118	0.127
TOTAL DEPTH (in)	0.543	0.508	0.513	0.493	0.463	0.532	2.281	1.868	0.756	0.465	0.387	0.416
TOTAL DEPTH (cm)	1.379	1.290	1.302	1.253	1.177	1.352	5.793	4.745	1.920	1.181	0.982	1.057

ANNUAL SUMMARY:

Sum of Mean Daily Flow 99.216 cfs = 2.810 cms
Total Depth 9.225 in = 23.431 cm
Maximum Instantaneous Flow 2.350 cfs = 0.067 cms on April 25 at 13.00 hours

*** Indicates some data were estimated during this day.**

HORSE CREEK STUDY AREA
WATERSHED: 206
WATERSHED AREA: 256 ACRES (103 HECTARES)

WATER YEAR 1978
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.188	0.159	0.449	0.320	0.278	0.424	4.452	2.598	1.235	0.490	0.311	0.238
2	0.165	0.269	2.600	0.316	0.277	0.428	3.862	2.480	1.182	0.497	0.304	0.231
3	0.153	0.187	1.858	0.314	0.289	0.429	3.048	2.281	1.110	0.492	0.297	0.224
4	0.139	0.180	1.281	0.313	0.289	0.428	2.424	2.021	1.036	0.759	0.290	0.216
5	0.126	0.198	0.963	0.312	0.295	0.438	2.040	1.765	0.971	0.618	0.281	0.228
6	0.131	0.194	0.818	0.312	0.343	0.426	1.855	1.583	0.914	0.570	0.275	0.233
7	0.224	0.182	0.712	0.309	0.314	0.409	1.705	1.490	0.861	0.885	0.270	0.316
8	0.196	0.170	0.607	0.320	0.309	0.423	1.582	1.488	0.813	0.774	0.264	0.273
9	0.242	0.170	0.544	0.335*	0.309	0.493	1.509	1.634	0.798	0.720	0.257	0.240
10	0.200	0.174	0.506	0.309*	0.309	0.483	1.520	2.034	0.881	0.687	0.254	0.232
11	0.182	0.174	0.521	0.293	0.309	0.497	1.760	2.233	0.798	0.635	0.252	0.283
12	0.173	0.175	0.496	0.285	0.309*	0.526	1.768	2.016	0.733	0.591	0.254	0.384
13	0.158	0.183	0.606	0.285	0.310*	0.531	1.693	1.980	0.700	0.559	0.367	0.285
14	0.149	0.214	0.839	0.288	0.312*	0.524	1.580	2.074	0.670	0.535	0.303	0.266
15	0.142	0.298	1.060	0.289	0.312*	0.508	1.553	2.063	0.650	0.530	0.346	0.251
16	0.134	0.235	1.133	0.289	0.307*	0.494	1.570	1.844	0.621	0.507	0.396	0.243
17	0.130	0.209*	1.068	0.298	0.298*	0.508	1.508	1.649	0.598	0.490	0.364	0.239
18	0.124	0.186*	0.926	0.302	0.296	0.552	1.468	1.531	0.618	0.469	0.312	0.254
19	0.119	0.164*	0.780	0.297	0.298	0.626	1.484	1.486	0.580	0.446	0.287	0.251
20	0.117	0.153	0.659	0.294	0.315	0.789	1.534	1.477	0.547	0.427	0.274	0.236
21	0.117	0.147	0.610	0.295	0.313	1.031	1.509	1.472	0.528	0.411	0.267	0.229
22	0.116	0.145	0.583	0.294	0.311	1.304	1.440	1.508	0.519	0.399	0.473	0.223
23	0.114	0.147*	0.540	0.291	0.315	1.650	1.354	1.395	0.508	0.388	0.328	0.218
24	0.112	0.155*	0.497	0.282	0.338	1.836	1.281	1.445	0.591	0.375	0.294	0.212
25	0.256	0.508*	0.462	0.280	0.368	1.772	1.437	1.455	0.698	0.358	0.277	0.208
26	0.221	0.473	0.434	0.290	0.388	1.698	1.870	1.484	0.552	0.349	0.263	0.205
27	0.157	0.344	0.403	0.287	0.405	1.965	2.326	1.529	0.516	0.341	0.255	0.201
28	0.149	0.318	0.374	0.282	0.418	2.799	2.477	1.554	0.490	0.405	0.249	0.212
29	0.144	0.455	0.382	0.279		3.474	2.642	1.528	0.600	0.358	0.244	0.208
30	0.160	0.376	0.373	0.273		4.047	2.718	1.418	0.519	0.334	0.243	0.203
31	0.154		0.348	0.273		4.413		1.335		0.321	0.244	
MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	4.891	6.942	23.431	9.205	8.930	35.924	58.967	53.851	21.834	15.719	9.092	7.242
TOTAL FLOW (cms days)	0.139	0.197	0.664	0.261	0.253	1.017	1.670	1.525	0.618	0.445	0.257	0.205
TOTAL DEPTH (in)	0.455	0.645	2.179	0.856	0.830	3.340	5.482	5.007	2.030	1.462	0.845	0.673
TOTAL DEPTH (cm)	1.155	1.639	5.533	2.174	2.109	8.484	13.925	12.717	5.156	3.712	2.147	1.710

ANNUAL SUMMARY:
Sum of Mean Daily Flow 256.029 cfs = 7.251 cms
Total Depth 23.804 in = 60.463 cm
Maximum Instantaneous Flow 4.550 cfs = 0.129 cms on April 1 at 23.30 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 206
WATERSHED AREA: 256 ACRES (103 HECTARES)

WATER YEAR 1979
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.206	0.146	0.146	0.149	0.123	0.162	0.384	2.928	0.593	0.281	0.139	0.152
2	0.198	0.145	0.148	0.146	0.121	0.161	0.357	3.003	0.564	0.267	0.138	0.140
3	0.195	0.140	0.158	0.143	0.121	0.162	0.334	3.033	0.535	0.256	0.137	0.132
4	0.176	0.147	0.220	0.140	0.119	0.161	0.320	3.235	0.509	0.250	0.136	0.129
5	0.159	0.138	0.172	0.137	0.120	0.191	0.354	3.989	0.495	0.238	0.132	0.125
6	0.158	0.138	0.166	0.129	0.122	0.332	0.381	3.486	0.525	0.233	0.128	0.122
7	0.156	0.139	0.167	0.129	0.126	0.399	0.475	2.726	0.489	0.230	0.130	0.120
8	0.152	0.433	0.159	0.129	0.128	0.318	0.505	2.321	0.452	0.221	0.130	0.118
9	0.150	0.191	0.149	0.126	0.127	0.271	0.561	1.980	0.426	0.218	0.125	0.122
10	0.148	0.133	0.146	0.125	0.136	0.252	0.563	1.795	0.405	0.212	0.123	0.140
11	0.147	0.111	0.150	0.128	0.158	0.246	0.552	1.761	0.388	0.210	0.121	0.122
12	0.144	0.123	0.153	0.129	0.223	0.246	0.518	1.803	0.376	0.204	0.122	0.115
13	0.144	0.128	0.151	0.130	0.413	0.249	0.490	1.979	0.361	0.195	0.129	0.112
14	0.143	0.128	0.151	0.129	0.258	0.250	0.457	2.198	0.352	0.190	0.131	0.110
15	0.143	0.127	0.150	0.130	0.206	0.268	0.448	2.475	0.342	0.185	0.183	0.108
16	0.143	0.126	0.150	0.131	0.191	0.300	0.483	2.495	0.336	0.180	0.140	0.106
17	0.143	0.132	0.149	0.132	0.181	0.303	0.676	2.210	0.354	0.175	0.129	0.105
18	0.142	0.141	0.149	0.131	0.176	0.296	0.763	1.970	0.399	0.171	0.158	0.103
19	0.142	0.142	0.158	0.130	0.176	0.286	0.786	1.761	0.362	0.166	0.156	0.101
20	0.141	0.142	0.159	0.129	0.170	0.281	0.728	1.600	0.337	0.163	0.135	0.101
21	0.142	0.142	0.156	0.130	0.170	0.279	0.668	1.493	0.467	0.162	0.137	0.100
22	0.139	0.142	0.152	0.132	0.168	0.279	0.687	1.376	0.356	0.178	0.123	0.100
23	0.139	0.142	0.154	0.131	0.167	0.283	0.754	1.267	0.322	0.164	0.258	0.097
24	0.139	0.141	0.156	0.131	0.166	0.304	0.886	1.197	0.305	0.159	0.174	0.096
25	0.138	0.142	0.154	0.132	0.165	0.332	1.051	1.024	0.292	0.154	0.140	0.095
26	0.137	0.141	0.154	0.132	0.165	0.332	1.220	0.930	0.280	0.153	0.142	0.099
27	0.136	0.141	0.155	0.130	0.165	0.350	1.521	0.850	0.273	0.150	0.135	0.096
28	0.137	0.140	0.156	0.129	0.161	0.446	2.052	0.799	0.263	0.158	0.131	0.093
29	0.140	0.140	0.155	0.130		0.461	2.544	0.732	0.260	0.153	0.136	0.093
30	0.142	0.142	0.154	0.128		0.439	2.864	0.680	0.267	0.145	0.213	0.092
31	0.138		0.154	0.127		0.399		0.636		0.141	0.257	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	4.653	4.462	4.849	4.082	4.720	9.038	24.382	59.730	11.686	5.961	4.566	3.343
TOTAL FLOW (cms days)	0.132	0.126	0.137	0.116	0.134	0.256	0.691	1.692	0.331	0.169	0.129	0.095
TOTAL DEPTH (in)	0.433	0.415	0.451	0.380	0.439	0.840	2.267	5.553	1.086	0.554	0.425	0.311
TOTAL DEPTH (cm)	1.099	1.054	1.145	0.964	1.115	2.134	5.758	14.106	2.760	1.408	1.078	0.789

ANNUAL SUMMARY:
Sum of Mean Daily Flow 141.472 cfs = 4.006 cms
Total Depth 13.153 in = 33.410 cm
Maximum Instantaneous Flow 4.090 cfs = 0.116 cms on May 5 at 16.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 206
WATERSHED AREA: 256 ACRES (103 HECTARES)

WATER YEAR 1980
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.096	0.123	0.120	0.147	0.174	0.287	0.164	1.302	1.100	0.477	0.251	0.177
2	0.095	0.118	0.217	0.149	0.144	0.277	0.163	1.232	1.290	0.689	0.243	0.215
3	0.095	0.127	0.239	0.146	0.227	0.274	0.162	1.765	1.182	0.747	0.242	0.198
4	0.095	0.138	0.256	0.142	0.181	0.301	0.163	2.036	1.206	0.720	0.236	0.167
5	0.095	0.150	0.182	0.141	0.167	0.284	0.179	1.624	1.112	0.706	0.229	0.158
6	0.093	0.140	0.163	0.141	0.167	0.267	0.181	1.294	1.124	0.674	0.225	0.147
7	0.094	0.129	0.213	0.140	0.166	0.258	0.169	1.039	1.004	0.618	0.217	0.147
8	0.093	0.124	0.192	0.137	0.166	0.248	0.167	0.908	0.928	0.579	0.211	0.144
9	0.093	0.119	0.194	0.140	0.166	0.240	0.189	0.809	0.867	0.744	0.206	0.140
10	0.094	0.116	0.233	0.139	0.165	0.250	0.195	0.718	0.830	0.631	0.202	0.138
11	0.094	0.118	0.162	0.137	0.163	0.247	0.211	0.632	0.812	0.568	0.199	0.287
12	0.094	0.117	0.157	0.228	0.149	0.229	0.220	0.573	0.902	0.536	0.193	0.168
13	0.094	0.116	0.151	0.302	0.136	0.219	0.299	0.527	0.920	0.512	0.191	0.263
14	0.094	0.114	0.146	0.358	0.136	0.219	0.401	0.487	0.930	0.593	0.184	0.238
15	0.147	0.112	0.150	0.264	0.135	0.213	0.527	0.504	0.988	0.502	0.181	0.174
16	0.120	0.116	0.143	0.227	0.135	0.202	0.610	0.534	0.940	0.465	0.175	0.162
17	0.144	0.181	0.297	0.212	0.136	0.202	0.812	0.475	0.909	0.440	0.173	0.153
18	0.168	0.142	0.244	0.199	0.167	0.199	1.199	0.434	0.849	0.421	0.322	0.176
19	0.252	0.130	0.197	0.185	0.214	0.194	1.632	0.400	0.771	0.399	0.205	0.267
20	0.154	0.129	0.187	0.181	0.215	0.194	1.999	0.376	0.709	0.379	0.195	0.431
21	0.153	0.129	0.184	0.176	0.187	0.194	2.362	0.361	0.654	0.361	0.183	0.412
22	0.157	0.129	0.179	0.172	0.178	0.187	2.223	0.408	0.627	0.344	0.177	0.270
23	0.176	0.127	0.170	0.169	0.174	0.185	2.393	0.447	0.579	0.325	0.171	0.234
24	0.150	0.124	0.171	0.169	0.171	0.178	2.628	0.440	0.534	0.314	0.167	0.213
25	0.151	0.123	0.165	0.167	0.171	0.176	2.397	0.633	0.496	0.305	0.163	0.197
26	0.146	0.121	0.159	0.154	0.184	0.176	2.041	0.990	0.533	0.293	0.162	0.185
27	0.132	0.119	0.151	0.146	0.239	0.173	2.113	1.398	0.524	0.281	0.159	0.176
28	0.130	0.117	0.144	0.179	0.311	0.171	2.129	1.489	0.448	0.273	0.157	0.168
29	0.134	0.115	0.141	0.258	0.306	0.171	2.063	1.403	0.421	0.264	0.155	0.159
30	0.130	0.115	0.140	0.320		0.168	1.649	1.305	0.401	0.261	0.150	0.154
31	0.126		0.146	0.296		0.164		1.230		0.254	0.170	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	3.885	3.779	5.594	5.920	5.226	6.745	31.639	27.773	24.589	14.672	6.090	6.119
TOTAL FLOW (cms days)	0.110	0.107	0.158	0.168	0.148	0.191	0.896	0.787	0.696	0.416	0.172	0.173
TOTAL DEPTH (in)	0.361	0.351	0.520	0.550	0.486	0.627	2.942	2.582	2.286	1.364	0.566	0.569
TOTAL DEPTH (cm)	0.917	0.892	1.321	1.398	1.234	1.593	7.472	6.559	5.807	3.465	1.438	1.445

ANNUAL SUMMARY:
Sum of Mean Daily Flow 142.030 cfs = 4.022 cms
Total Depth 13.205 in = 33.541 cm
Maximum Instantaneous Flow 3.520 cfs = 0.100 cms on May 2 at 21.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 206
WATERSHED AREA: 256 ACRES (103 HECTARES)

WATER YEAR 1981
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.153	0.126	0.155	0.821	0.261	0.496	0.738	0.757	0.667	0.775	0.266	0.206
2	0.149	0.146	0.195	0.741	0.254	0.488	0.697	0.727	0.633	0.719	0.259	0.202
3	0.147	0.133	0.231	0.674	0.247	0.477	0.693	0.686	0.600	0.668	0.250	0.179
4	0.144	0.132	0.231	0.610	0.241	0.469	0.631	0.663	0.613	0.628	0.251	0.170
5	0.141	0.125	0.196	0.556	0.234	0.446	0.624	0.654	0.669	0.600	0.248	0.163
6	0.138	0.216	0.186	0.502	0.230	0.433	0.589	0.613	0.811	0.758	0.241	0.160
7	0.134	0.391	0.173	0.479	0.225	0.422	0.563	0.580	0.823	0.775	0.233	0.156
8	0.133	0.244	0.158	0.438	0.218	0.417	0.541	0.556	1.571	0.606	0.224	0.152
9	0.132	0.245	0.158	0.417	0.213	0.408	0.521	0.527	2.034	0.558	0.219	0.149
10	0.132	0.228	0.159	0.404	0.209	0.404	0.490	0.527	2.008	0.530	0.216	0.147
11	0.131	0.201	0.159	0.394	0.208	0.403	0.486	0.578	1.797	0.507	0.212	0.146
12	0.145	0.184	0.160	0.384	0.208	0.410	0.476	0.534	1.829	0.486	0.209	0.145
13	0.143	0.163	0.163*	0.340	0.221	0.431	0.457	0.501	1.973	0.467	0.205	0.142
14	0.140	0.182	0.162*	0.331	0.349	0.449	0.464	0.494	2.130	0.448	0.200	0.140
15	0.143	0.146	0.187*	0.331	0.257	0.475	0.543	0.556	1.916	0.430	0.194	0.137
16	0.141	0.138	0.200	0.299	0.611	0.529	0.577	0.516	2.065	0.412	0.189	0.134
17	0.139	0.146	0.210	0.295	0.584	0.540	0.647	0.500	2.145	0.397	0.183	0.131
18	0.138	0.155	0.201	0.293	0.603	0.537	0.816	0.481	2.164	0.393	0.183	0.130
19	0.136	0.156	0.190	0.291	0.659	0.543	1.063	0.468	2.267	0.376	0.206	0.180
20	0.134	0.152	0.188	0.279	0.646	0.546	1.183	0.466	2.387	0.358	0.199	0.158
21	0.133	0.175	0.247	0.269	0.644	0.528	1.158	0.833	2.365	0.347	0.184	0.160
22	0.133	0.183	0.519	0.265	0.632	0.526	1.126	0.788	2.074	0.335	0.176	0.149
23	0.130	0.150	0.390	0.368	0.600	0.520	1.157	0.852	1.777	0.325	0.171	0.147
24	0.130	0.145	0.404	0.383	0.584	0.512	1.215	0.847	1.509	0.315	0.167	0.142
25	0.132	0.135	1.226	0.306	0.562	0.639	1.087	0.929	1.328	0.335	0.164	0.200
26	0.146	0.142	2.537	0.337	0.532	0.670	0.998	0.877	1.183	0.318	0.163	0.165
27	0.136	0.168	2.169	0.293	0.516	0.744	0.915	0.841	1.067	0.299	0.160	0.323
28	0.130	0.179	1.698	0.304	0.505	0.771	0.898	0.803	0.976	0.290	0.157	0.245
29	0.129	0.167	1.248	0.291		0.806	0.844	0.756	0.893	0.280	0.154	0.185
30	0.129	0.158	1.084	0.278		0.778	0.802	0.785	0.834	0.274	0.329	0.169
31	0.128		0.912	0.273		0.776		0.745		0.271	0.207	
MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	4.249	5.211	16.092	12.243	11.255	16.592	22.998	20.437	45.105	14.278	6.419	5.010
TOTAL FLOW (cms days)	0.120	0.148	0.456	0.347	0.319	0.470	0.651	0.579	1.277	0.404	0.182	0.142
TOTAL DEPTH (in)	0.395	0.484	1.496	1.138	1.046	1.543	2.138	1.900	4.194	1.328	0.597	0.466
TOTAL DEPTH (cm)	1.003	1.231	3.800	2.891	2.658	3.918	5.431	4.826	10.652	3.372	1.516	1.183

ANNUAL SUMMARY:

Sum of Mean Daily Flow 179.888 cfs = 5.094 cms
Total Depth 16.725 in = 42.482 cm
Maximum Instantaneous Flow 3.010 cfs = 0.085 cms on June 16 at 18.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 206
WATERSHED AREA: 256 ACRES (103 HECTARES)

WATER YEAR 1982
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.158	0.166	0.196	0.183	0.196	0.421	0.424*	1.995	2.286	0.788	0.332	0.178
2	0.157	0.157	0.197	0.183	0.199	0.418	0.424	2.403	2.392	0.673	0.330	0.172
3	0.154	0.154	0.198	0.183	0.199	0.407	0.424	3.132	2.397	0.648	0.317	0.176
4	0.150	0.153	0.190	0.183	0.199	0.401	0.423	2.860	2.405	0.649	0.278	0.171
5	0.148	0.153	0.195	0.183	0.200	0.387*	0.418	2.368	2.246	0.658	0.265	0.172
6	0.144	0.152	0.296	0.184	0.200	0.380*	0.416	2.024	1.998	0.610	0.256	0.166
7	0.167	0.153	0.272	0.184	0.200	0.379*	0.408	2.001	2.017	0.621	0.250	0.159
8	0.166	0.154	0.240	0.184	0.199	0.377*	0.396	2.116	1.819	0.608	0.253	0.161
9	0.243	0.154	0.251	0.183	0.199	0.430*	0.387	2.193	1.737	0.606	0.245	0.158
10	0.291	0.152	0.282	0.184	0.199	0.459*	0.381	2.143	1.739	0.569	0.240	0.272
11	0.305	0.150	0.246	0.185	0.199	0.494*	0.479	2.114	1.726	0.540	0.245	0.203
12	0.242	0.217	0.233	0.186	0.199	0.495*	0.639	2.177	1.702	0.518	0.249	0.233
13	0.203	0.192	0.226	0.188	0.213	0.494*	0.719	2.422	1.582	0.570	0.237	0.190
14	0.185	0.192	0.219	0.187	0.299*	0.499*	0.868	3.118	1.522	0.544	0.228	0.169
15	0.175	0.170	0.212	0.185	0.413*	0.506*	0.929	3.731	1.341	0.490	0.223	0.161
16	0.171	0.175	0.209	0.185	0.513	0.492*	0.931	3.759	1.209	0.498	0.219	0.155
17	0.167	0.238	0.209	0.185	0.511	0.473*	0.886	3.956	1.097	0.463	0.212	0.147
18	0.162	0.205	0.209	0.189	0.501	0.463*	0.815	4.306	1.012	0.444	0.207	0.141
19	0.157	0.184	0.209	0.189	0.551	0.448*	0.745	3.827	0.942	0.428	0.202	0.136
20	0.152	0.186	0.209	0.190	0.623	0.429*	0.696	3.340	0.881	0.415	0.236	0.147
21	0.150	0.237	0.210	0.187	0.719	0.423*	0.661	3.458	0.828	0.400	0.232	0.131
22	0.150	0.229	0.210	0.186	0.724	0.412*	0.677	3.952	0.789	0.387	0.204	0.128
23	0.150	0.204	0.210	0.187	0.673	0.404*	0.810	4.096	0.757	0.375	0.193	0.125
24	0.150	0.195	0.210	0.194	0.624	0.403*	1.105	3.947	0.712	0.367	0.189	0.127
25	0.150	0.195	0.210	0.196	0.589	0.415*	1.456	4.182	0.686	0.363	0.186	0.129
26	0.222	0.195	0.211	0.197	0.566	0.433*	1.588	4.223	0.658	0.356	0.182	0.189
27	0.182	0.195	0.210	0.196	0.490	0.441*	1.654	3.532	0.637	0.342	0.180	0.215
28	0.163	0.196	0.206	0.197	0.436	0.441*	1.800	3.003	0.745	0.332	0.176	0.288
29	0.164	0.195	0.201	0.197		0.427*	1.963	2.591	0.681	0.324	0.175	0.196
30	0.167	0.196	0.195	0.197		0.426*	1.988	2.413	0.615	0.318	0.230	0.162
31	0.174		0.189	0.197		0.423*		2.219		0.324	0.190	

MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	5.517	5.491	6.759	5.835	10.829	13.500	25.507	93.597	41.156	15.227	7.159	5.155
TOTAL FLOW (cms days)	0.156	0.156	0.191	0.165	0.307	0.382	0.722	2.651	1.166	0.431	0.203	0.146
TOTAL DEPTH (in)	0.513	0.511	0.628	0.542	1.007	1.255	2.372	8.702	3.826	1.416	0.666	0.479
TOTAL DEPTH (cm)	1.303	1.297	1.596	1.378	2.557	3.188	6.024	22.104	9.719	3.596	1.691	1.217

ANNUAL SUMMARY:
Sum of Mean Daily Flow 235.733 cfs = 6.676 cms
Total Depth 21.917 in = 55.670 cm
Maximum Instantaneous Flow 4.430 cfs = 0.125 cms on May 25 at 16.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 206
WATERSHED AREA: 256 ACRES (103 HECTARES)

WATER YEAR 1983
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.177	0.233	0.176	0.161	0.202	0.484	0.469	0.895	0.391	0.368	0.170	0.206
2	0.169	0.217	0.171	0.162	0.198	0.542	0.473	0.879	0.388	0.369	0.166	0.198
3	0.330	0.206	0.180	0.163	0.197	0.587*	0.459	0.824	0.369	0.317	0.162	0.146
4	0.230	0.210	0.329	0.167	0.196	0.626*	0.451	0.775	0.349	0.272	0.159	0.138
5	0.216	0.215	0.220	0.364	0.193	0.713*	0.507	0.875	0.332	0.254	0.154	0.135
6	0.194	0.235	0.213	0.317	0.189	0.771*	0.419	0.836	0.318	0.242	0.150	0.130
7	0.260	0.207	0.196	0.434	0.187	0.779*	0.415	0.742	0.307	0.233	0.157	0.126
8	0.261	0.192	0.181	0.400	0.186	0.789*	0.406	0.737	0.304	0.221	0.162	0.126
9	0.232	0.195	0.182	0.347	0.186	0.849	0.403	0.688	0.288	0.228	0.281	0.124
10	0.216	0.192	0.179	0.319	0.185	0.990	0.395	0.682	0.310	0.289	0.201	0.229
11	0.210	0.188	0.177	0.295	0.186	1.197	0.383	0.629	0.298	0.229	0.258	0.248
12	0.198	0.185	0.178	0.281	0.193	1.265	0.376	0.605	0.336	0.214	0.183	0.159
13	0.188	0.183	0.182	0.269	0.197	1.239	0.363	0.591	0.286	0.209	0.167	0.144
14	0.180	0.180	0.181	0.258	0.192	1.149	0.359	0.578	0.258	0.382	0.189	0.137
15	0.174	0.176	0.185	0.250	0.191	1.040	0.363	0.648	0.282	0.261	0.182	0.134
16	0.169	0.181	0.216	0.246	0.203	0.937	0.384	0.652	0.250	0.241	0.168	0.131
17	0.184	0.198	0.222	0.238	0.233	0.851	0.450	0.681	0.290	0.226	0.155	0.128
18	0.192	0.203	0.197	0.234	0.452	0.765	0.551	0.766	0.352	0.218	0.146	0.155
19	0.186	0.200	0.192	0.231	0.388	0.688	0.676	0.768	0.284	0.212	0.144	0.172
20	0.193	0.189	0.191	0.222	0.360	0.728	0.850	0.763	0.265	0.247	0.143	0.144
21	0.198	0.185	0.197	0.217	0.353	0.601	1.025	0.747	0.256	0.213	0.147	0.140
22	0.192	0.172	0.197	0.214	0.373	0.568	1.157	0.706	0.246	0.198	0.176	0.135
23	0.181	0.163	0.192	0.212	0.381	0.544	1.348	0.663	0.240	0.195	0.166	0.131
24	0.181	0.163	0.182	0.211	0.416	0.508	1.653	0.618	0.235	0.232	0.155	0.128
25	0.185	0.171	0.174	0.200	0.457	0.500	1.451	0.577	0.230	0.217	0.144	0.126
26	0.222	0.171	0.178	0.197	0.488	0.472	1.188	0.539	0.225	0.199	0.138	0.124
27	0.223	0.175	0.174	0.217	0.495	0.449	1.014	0.505	0.251	0.190	0.135	0.125
28	0.204	0.188	0.169	0.214	0.491	0.434	0.926	0.471	0.244	0.184	0.132	0.124
29	0.251	0.190	0.169	0.206		0.445	0.894	0.441	0.262	0.179	0.129	0.124
30	0.253	0.183	0.165	0.204		0.522	0.900	0.418	0.248	0.175	0.125	0.137
31	0.231		0.161	0.203		0.480		0.403		0.173	0.131	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	6.475	5.744	5.905	7.649	7.968	22.511	20.706	20.701	8.694	7.384	5.074	4.404
TOTAL FLOW (cms days)	0.183	0.163	0.167	0.217	0.226	0.638	0.586	0.586	0.246	0.209	0.144	0.125
TOTAL DEPTH (in)	0.602	0.534	0.549	0.711	0.741	2.093	1.925	1.925	0.808	0.687	0.472	0.409
TOTAL DEPTH (cm)	1.529	1.357	1.395	1.806	1.882	5.316	4.890	4.889	2.053	1.744	1.198	1.040

ANNUAL SUMMARY:
Sum of Mean Daily Flow 123.215 cfs = 3.489 cms
Total Depth 11.456 in = 29.098 cm
Maximum Instantaneous Flow 1.740 cfs = 0.049 cms on April 24 at 1.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 206
WATERSHED AREA: 256 ACRES (103 HECTARES)

WATER YEAR 1984
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.137	0.132	0.131*	0.172	0.288*	0.227*	0.473*	0.993*	3.184	0.624	0.288	0.213
2	0.133	0.164	0.131*	0.191	0.274*	0.239*	0.462*	1.097*	2.710	0.600	0.277	0.180
3	0.131	0.145	0.131*	0.677	0.269	0.229*	0.452*	1.063	2.287	0.577	0.269	0.171
4	0.127	0.214	0.131*	0.641	0.264	0.223*	0.462*	1.092	2.270	0.558	0.262	0.166
5	0.125	0.159	0.131*	0.522	0.261	0.219*	0.543*	1.116	2.132	0.539	0.261	0.162
6	0.122	0.250	0.131*	0.516	0.255	0.218*	0.632*	1.077	2.074	0.522	0.263	0.211
7	0.120	0.193	0.135*	0.471	0.250	0.218*	0.642*	1.053	2.248	0.504	0.253	0.179
8	0.122	0.170	0.141*	0.443	0.248	0.221*	0.706*	1.109	2.153	0.488	0.246	0.224
9	0.180	0.160	0.146*	0.399	0.244*	0.245*	0.730*	1.793	2.059	0.471	0.241	0.182
10	0.144	0.168	0.153*	0.371	0.240*	0.281*	0.741*	2.220	1.954	0.454	0.239	0.169
11	0.132	0.221	0.160*	0.349	0.234*	0.319*	0.722*	2.252	2.027	0.436	0.235	0.166
12	0.127	0.241	0.168*	0.329	0.235*	0.304*	0.696*	2.850	1.832	0.413	0.232	0.161
13	0.125	0.222	0.177*	0.313	0.368*	0.318*	0.673*	3.723	1.724	0.402	0.227	0.155
14	0.125	0.198	0.185*	0.296	0.336*	0.447	0.725*	5.198	1.578	0.391	0.221	0.151
15	0.125	0.205	0.189*	0.278	0.302*	0.454	1.073*	4.831	1.462	0.377	0.217	0.149
16	0.126	0.214	0.186	0.273	0.295*	0.492	1.887*	3.707	1.342	0.364	0.217	0.147
17	0.150	0.221	0.184	0.263	0.284*	0.497	2.188*	3.076	1.218	0.355	0.235	0.144
18	0.169	0.207	0.183	0.250	0.274*	0.490	2.191*	2.976	1.131	0.361	0.229	0.140
19	0.138	0.191	0.180	0.238	0.267*	0.541	2.188*	3.453	1.051	0.351	0.211	0.139
20	0.131	0.186	0.172	0.228	0.265*	0.763	2.190*	4.400	1.025	0.342	0.202	0.341
21	0.127	0.175	0.165	0.225	0.263*	0.892	2.188*	4.036	1.157	0.332	0.197	0.278
22	0.178	0.169	0.159	0.224	0.256*	0.917	2.204*	3.358	0.958	0.325	0.194	0.211
23	0.207	0.163*	0.161	0.226	0.244*	0.864	2.184*	4.056	0.881	0.317	0.192	0.232
24	0.150	0.180*	0.166	0.452	0.239*	0.806	2.191*	3.857	0.839	0.314	0.189	0.210
25	0.140	0.172*	0.175	0.626	0.237*	0.729	2.021*	3.245	0.833	0.311	0.186	0.191
26	0.134	0.156*	0.167	0.426	0.229*	0.678	1.723*	3.347	0.769	0.368	0.182	0.185
27	0.129	0.154*	0.164	0.397*	0.226*	0.620	1.473*	3.534	0.734	0.339	0.175	0.176
28	0.127	0.157*	0.162	0.379*	0.225*	0.573	1.296*	3.648	0.707	0.409	0.165	0.170
29	0.128	0.140*	0.162	0.354*	0.224*	0.538	1.137*	4.228	0.688	0.339	0.159	0.166
30	0.128	0.132*	0.169	0.328*		0.513	1.024*	5.095	0.655	0.316	0.187	0.163
31	0.129		0.171	0.306*		0.494		4.118		0.295	0.265	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	4.266	5.459	4.963	11.160	7.596	14.569	37.816	91.598	45.681	12.789	6.915	5.533
TOTAL FLOW (cms days)	0.121	0.155	0.141	0.316	0.215	0.413	1.071	2.594	1.294	0.362	0.196	0.157
TOTAL DEPTH (in)	0.397	0.508	0.461	1.038	0.706	1.355	3.516	8.516	4.247	1.189	0.643	0.514
TOTAL DEPTH (cm)	1.007	1.289	1.172	2.636	1.794	3.441	8.931	21.631	10.788	3.020	1.633	1.307

ANNUAL SUMMARY:
Sum of Mean Daily Flow 248.344 cfs = 7.033 cms
Total Depth 23.090 in = 58.648 cm
Maximum Instantaneous Flow 6.520 cfs = 0.185 cms on May 30 at 13.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 206
WATERSHED AREA: 256 ACRES (103 HECTARES)

WATER YEAR 1985
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.173	0.193	0.159	0.159	0.157	0.159	0.338	1.987	0.652	0.225	0.263	0.114
2	0.168	0.200	0.159	0.159	0.158	0.160	0.421	2.362	0.614	0.219	0.431	0.131
3	0.166	0.206	0.159	0.159	0.158	0.162	0.431	2.194	0.574	0.209	0.201	0.126
4	0.162	0.213	0.159	0.159	0.158	0.162	0.401	1.688	0.618	0.204	0.181	0.118
5	0.170	0.205	0.159	0.159	0.159	0.161	0.382	1.351	0.681	0.200	0.171	0.116
6	0.163	0.259	0.159	0.159	0.160	0.161	0.413	1.223	0.662	0.198	0.151	0.206
7	0.159	0.264	0.159	0.159	0.159	0.161	0.467	1.176	0.668	0.200	0.147	0.190
8	0.156	0.239	0.159	0.159	0.159	0.161	0.636	1.107	0.638	0.198	0.150	0.588
9	0.154	0.227	0.158	0.158	0.160	0.161	0.807	1.016	0.594	0.190	0.143	0.377
10	0.152	0.220	0.158	0.158	0.160	0.161	1.008	0.975	0.558	0.190	0.183	0.283
11	0.195	0.229	0.158	0.157	0.161	0.161	1.378	0.902	0.519	0.175	0.198	0.338
12	0.180	0.269	0.158	0.158	0.161	0.161	1.436	0.786	0.485	0.168	0.256	0.482
13	0.231	0.330	0.158	0.157	0.161	0.161	1.535	0.724	0.455	0.163	0.191	0.255
14	0.181	0.294	0.157	0.158	0.161	0.161	1.872	0.790	0.433	0.160	0.162	0.216
15	0.175	0.249	0.157	0.158	0.161	0.161	2.308	0.734	0.411	0.158	0.150	0.248
16	0.168	0.235	0.157	0.158	0.161	0.162	2.497	0.732	0.387	0.154	0.142	0.216
17	0.166	0.225	0.157	0.159	0.161	0.162	2.360	0.708	0.365	0.152	0.137	0.282
18	0.166	0.218	0.157	0.158	0.162	0.163	2.050	0.664	0.346	0.148	0.142	0.223
19	0.169	0.217	0.157	0.158	0.159	0.163	1.684	0.608	0.331	0.145	0.148	0.208
20	0.185	0.213	0.157	0.159	0.160	0.163	1.371	0.559	0.319	0.142	0.142	0.195
21	0.191	0.208	0.156	0.159	0.160	0.161	1.138	0.516	0.306	0.140	0.185	0.189
22	0.192	0.205	0.157	0.158	0.160	0.167	0.967	0.473	0.294	0.137	0.142	0.178
23	0.192	0.198	0.157	0.158	0.160	0.172	0.844	0.454	0.284	0.134	0.133	0.168
24	0.175	0.191	0.157	0.157	0.159	0.182	0.747	0.469	0.275	0.133	0.129	0.162
25	0.195	0.186	0.157	0.157	0.160	0.191	0.676	0.442	0.270	0.131	0.126	0.158
26	0.275	0.178	0.158	0.158	0.160	0.197	0.636	0.402	0.264	0.128	0.124	0.154
27	0.225	0.170	0.157	0.157	0.159	0.201	0.717	0.386	0.255	0.125	0.122	0.148
28	0.200	0.163	0.157	0.157	0.160	0.207	0.847	0.461	0.246	0.123	0.121	0.146
29	0.193	0.159	0.158	0.157		0.212	1.179	0.592	0.240	0.143	0.118	0.146
30	0.188	0.158	0.158	0.157		0.220	1.537	0.671	0.232	0.143	0.115	0.146
31	0.192		0.159	0.157		0.297		0.575		0.170	0.115	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	5.657	6.520	4.888	4.899	4.471	5.433	33.080	27.724	12.973	5.105	5.117	6.505
TOTAL FLOW (cms days)	0.160	0.185	0.138	0.139	0.127	0.154	0.937	0.785	0.367	0.145	0.145	0.184
TOTAL DEPTH (in)	0.526	0.606	0.454	0.455	0.416	0.505	3.076	2.578	1.206	0.475	0.476	0.605
TOTAL DEPTH (cm)	1.336	1.540	1.154	1.157	1.056	1.283	7.812	6.547	3.064	1.206	1.208	1.536

ANNUAL SUMMARY:
Sum of Mean Daily Flow 122.370 cfs = 3.466 cms
Total Depth 11.377 in = 28.899 cm
Maximum Instantaneous Flow 4.430 cfs = 0.125 cms on September 8 at 20.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 208
WATERSHED AREA: 364 ACRES (147 HECTARES)

WATER YEAR 1975
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.228	0.258	0.232	0.178	0.220	0.330	0.264	0.458	7.196	1.331	0.609	0.441
2	0.223	0.248	0.229	0.178	0.220	0.374	0.264	0.563	7.945	1.282	0.583	0.424
3	0.223	0.237	0.231	0.179	0.220	0.321	0.263	0.642	8.210	1.205	0.559	0.405
4	0.224	0.231	0.232	0.180	0.218	0.305	0.260	0.582	7.267	1.145	0.539	0.394
5	0.224	0.230	0.201	0.182	0.216	0.290	0.255	0.563	6.959	1.092	0.517	0.382
6	0.225	0.243	0.189*	0.182	0.220	0.281	0.251	0.570	7.420	1.048	0.459	0.366
7	0.226	0.260	0.187*	0.182	0.222	0.271	0.251	0.737	7.254	1.015	0.562	0.364
8	0.227	0.259	0.187*	0.181	0.223	0.270	0.251	0.882	6.871	0.971	0.502	0.356
9	0.232	0.236	0.187*	0.180	0.223	0.277	0.251	1.053	6.060	0.930	0.483	0.350
10	0.230	0.237	0.186	0.179	0.223	0.289	0.255	1.543	5.553	0.890	0.458	0.344
11	0.261	0.229	0.201	0.176	0.223	0.289	0.271	2.092	5.421	0.858	0.451	0.338
12	0.244	0.257	0.193*	0.175	0.224	0.290	0.295	2.355	5.314	0.841	0.446	0.333
13	0.235	0.278	0.192*	0.181	0.232	0.291	0.320	2.673	4.931	0.845	0.436	0.331
14	0.230	0.248	0.189*	0.204	0.234	0.291	0.355	3.640	4.376	0.839	0.424	0.327
15	0.229	0.238	0.188	0.221	0.230	0.291	0.457	5.291	4.035	0.837	0.415	0.309
16	0.227	0.229	0.227	0.198	0.225	0.291	0.453	5.688	3.462	0.801	0.407	0.324
17	0.224	0.236	0.211	0.959	0.223	0.286	0.402	5.075	3.038	0.747	0.510	0.544
18	0.222	0.264	0.199	1.213	0.221	0.288	0.385	4.803	2.771	0.725	0.594	0.373
19	0.220	0.250	0.196	0.464	0.220	0.300	0.381	4.490	2.534	0.711	0.573	0.349
20	0.219	0.274	0.222	0.367	0.220	0.291	0.396	3.781	2.769	0.692	0.576	0.334
21	0.293	0.298	0.267	0.329	0.218	0.288	0.402	3.213	2.332	0.676	0.483	0.327
22	0.277	0.306	0.210	0.284	0.216	0.286	0.447	2.824	2.097	0.652	0.486	0.314
23	0.253	0.251	0.203	0.322	0.216	0.281	0.492	3.039	1.933	0.639	1.053	0.309
24	0.242	0.270	0.193	0.315	0.216	0.279	0.479	3.208	1.898	0.624	0.885	0.294*
25	0.235	0.282	0.192	0.280	0.218	0.276	0.510	3.104	1.808	0.596	0.619	0.284*
26	0.231	0.249	0.189	0.263	0.220	0.268	0.472	2.800	1.671	0.587	0.544	0.271*
27	0.229	0.244	0.188	0.251	0.220	0.268	0.465	2.668	1.637	0.578	0.512	0.265
28	0.240	0.241*	0.185	0.246	0.312	0.266	0.446	2.855	1.496	0.573	0.548	0.265
29	0.234	0.237*	0.180	0.237		0.265	0.447	3.593	1.401	0.677	0.466	0.265
30	0.230	0.235*	0.179	0.230		0.265	0.456	4.761	1.337	0.700	0.440	0.266
31	0.231		0.178	0.224		0.264		6.102		0.633	0.453	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	7.268	7.552	6.244	8.936	6.291	8.924	10.894	85.644	126.994	25.737	16.590	10.250
TOTAL FLOW (cms days)	0.206	0.214	0.177	0.253	0.178	0.253	0.309	2.425	3.596	0.729	0.470	0.290
TOTAL DEPTH (in)	0.475	0.494	0.408	0.584	0.411	0.584	0.712	5.600	8.304	1.683	1.085	0.670
TOTAL DEPTH (cm)	1.207	1.254	1.037	1.484	1.045	1.482	1.809	14.225	21.092	4.275	2.755	1.702

ANNUAL SUMMARY:
Sum of Mean Daily Flow 321.325 cfs = 9.100 cms
Total Depth 21.011 in = 53.368 cm
Maximum Instantaneous Flow 8.460 cfs = 0.240 cms on June 3 at 4.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 208
WATERSHED AREA: 364 ACRES (147 HECTARES)

WATER YEAR 1976
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.268	0.631	1.736	1.636	0.859	0.561	0.563	2.258	2.363	0.973	0.547*	0.380
2	0.266	0.717	2.183	1.280	0.846	0.561	0.563	2.892	2.193	0.946	0.541*	0.370
3	0.261	0.864	1.941	0.815	0.845	0.561	0.563	3.829	2.058	0.906	0.520*	0.355
4	0.421	0.980	1.915	0.811	0.924	0.561	0.563	4.957	1.918	0.869	0.501*	0.350
5	0.313	1.038	1.826	0.797	0.881	0.561	0.641	5.604	1.820	0.836	0.485*	0.348
6	0.339	1.027	1.719	0.786	0.926	0.561	0.866	5.336	1.767	0.801	0.471	0.569
7	0.477	1.017	1.956	0.772	0.926	0.561	0.929	5.384	1.705	0.781	0.702	0.397
8	0.369	0.907	2.254	0.784	0.926	0.561	1.243	6.076	1.605	0.769	0.774	0.373
9	0.336	0.815	2.473	0.747	0.926	0.561	1.678	6.883	1.482	0.744	0.588	0.360
10	0.324	0.754	2.508	0.733	0.926	0.561	1.977	7.552	1.512	0.723	0.531	0.351
11	0.419	0.710	2.333	0.717	0.926	0.561	2.239	8.408	1.378	0.700	0.493	0.377
12	0.461	0.716	2.135	0.703	0.926	0.561	2.567	8.125	1.375	1.046	0.473	0.387
13	0.413	0.633	1.918	0.600	0.926	0.561	2.873	7.251	1.373	0.749	0.470	0.355
14	0.399	0.631	1.702	0.674	0.926	0.561	2.829	7.345	1.321	0.699	0.459	0.340
15	0.422	0.674	1.560	1.070	0.925	0.561	2.696	7.113	1.242	0.666	0.550	0.331
16	0.389	0.639	1.416	1.206	0.920	0.561	2.381	6.494	1.507	0.584	0.567	0.334
17	0.368	0.590*	1.304	1.127	0.898	0.561	2.108	6.289	1.553	0.584	0.486	0.358
18	0.395	0.553*	1.212	1.119	0.879	0.561	1.929	5.618	1.410	0.646	0.494	0.344
19	0.397*	0.637	1.132	1.119	0.872	0.563	1.753	5.192	1.345	0.596	0.467	0.330
20	0.482*	0.584	1.082	1.119	0.872	0.563	1.668	4.862	1.396	0.564*	0.435	0.317
21	0.971*	0.549	1.037	1.119	0.872	0.563	1.616	4.531	1.456	0.539*	0.431	0.310
22	0.679*	0.534	0.994	1.109	0.872	0.563	1.582	4.382	1.415	0.511*	0.449	0.308
23	0.585*	0.500	0.959	1.088	0.870	0.563	1.519	4.407	1.353	0.506*	0.508	0.362
24	0.541*	0.684	0.948	1.062	0.812	0.563	1.590	4.259	1.295	0.601*	0.442	0.327
25	0.517*	0.580	0.943	1.032	0.662	0.563	1.618	4.280	1.253	0.500*	0.493	0.316
26	0.522*	0.538	0.972	1.001	0.556	0.563	1.594	3.635	1.219	0.489*	0.599	0.309
27	0.490*	0.534	0.926	0.968	0.556	0.563	1.579	3.504	1.161	0.487*	0.465	0.305
28	0.483*	0.528	0.870	0.942	0.557	0.563	1.537	3.348	1.102	0.484*	0.437	0.300
29	0.514*	0.510	0.872	0.928	0.561	0.563	1.621	2.937	1.058	0.482*	0.414	0.295
30	0.647*	0.454	0.887	0.898		0.563	1.822	2.753	1.005	0.479*	0.398	0.292
31	0.669		1.004	0.868		0.563		2.640		0.476*	0.386	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	14.136	20.527	46.713	29.631	24.374	17.414	48.706	158.142	44.642	20.734	15.576	10.449
TOTAL FLOW (cms days)	0.400	0.581	1.323	0.839	0.690	0.493	1.379	4.479	1.264	0.587	0.441	0.296
TOTAL DEPTH (in)	0.924	1.342	3.055	1.938	1.594	1.139	3.185	10.341	2.919	1.356	1.019	0.683
TOTAL DEPTH (cm)	2.348	3.409	7.758	4.921	4.048	2.892	8.090	26.265	7.414	3.444	2.587	1.736

ANNUAL SUMMARY:
Sum of Mean Daily Flow 451.044 cfs = 12.774 cms
Total Depth 29.493 in = 74.913 cm
Maximum Instantaneous Flow 9.100 cfs = 0.258 cms on May 11 at 20.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 208
WATERSHED AREA: 364 ACRES (147 HECTARES)

WATER YEAR 1977
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.289	0.508	0.265	0.230	0.210	0.243	0.230	1.914	0.585	0.282	0.194	0.249
2	0.419	0.428	0.262	0.230	0.206	0.237	0.234	1.733	0.564	0.326	0.189	0.227
3	0.401	0.403	0.265	0.230	0.205	0.235	0.236	1.482	0.533	0.300	0.188	0.215
4	0.337	0.393	0.252	0.230	0.203	0.234	0.273	1.232	0.511	0.317	0.187	0.206
5	0.329	0.383	0.237	0.230	0.202	0.230	0.343	1.096	0.490	0.301	0.185	0.202
6	0.319	0.374	0.228	0.230	0.200	0.229	0.443	1.005	0.469	0.297	0.184	0.198
7	0.297	0.363	0.253	0.230	0.199	0.230	0.624	1.029	0.458	0.270	0.182	0.192
8	0.293	0.360	0.276	0.230	0.199	0.232	0.874	1.043	0.574	0.257	0.179	0.186
9	0.293	0.361	0.275	0.230	0.199	0.235*	0.873	0.965	0.469	0.256	0.174	0.178
10	0.325	0.361	0.266	0.230	0.199	0.237*	0.789	0.966	0.441	0.252	0.172	0.178
11	0.433	0.355	0.265	0.230	0.199	0.238*	0.738	0.896	0.458	0.242	0.170	0.177
12	0.347	0.342	0.263	0.195	0.207	0.239	0.765	0.827	0.466	0.235	0.166	0.175
13	0.335	0.327	0.262	0.187	0.235	0.238	0.786	0.761	0.489	0.235	0.165	0.174
14	0.326	0.304	0.252	0.188	0.223	0.235*	0.734	0.731	0.451	0.232	0.165	0.172
15	0.313	0.279	0.246	0.192	0.218	0.233*	0.734	0.708	0.422	0.226	0.164	0.263
16	0.313	0.324	0.245	0.202	0.217	0.230*	0.761	0.722	0.397	0.223	0.159	0.329
17	0.311	0.306	0.245	0.252	0.217	0.230	0.720	0.816	0.378	0.220	0.156	0.305
18	0.304	0.414	0.245	0.356	0.225	0.230	0.705	0.847	0.361	0.334	0.155	0.228
19	0.299	0.319	0.236	0.308	0.240	0.230*	0.671	0.951	0.352	0.277	0.154	0.219
20	0.298	0.302	0.232	0.264	0.252	0.230*	0.660	0.937	0.366	0.243	0.149	0.370
21	0.295	0.288	0.230	0.255*	0.271	0.232*	0.731	0.929	0.356	0.236	0.147	0.357
22	0.291	0.286	0.230	0.244*	0.263	0.237*	0.915	0.907	0.338	0.219	0.181	0.283
23	0.289	0.286	0.226	0.233*	0.244	0.250*	1.319	0.888	0.324	0.218	0.157	0.248
24	0.289	0.300	0.223	0.224*	0.226	0.249*	1.982	0.863	0.309	0.303	0.220	0.255
25	0.401	0.363	0.223	0.216*	0.225	0.241*	2.645	0.806	0.301	0.274	0.288	0.276
26	0.382	0.260*	0.238	0.212	0.243	0.240*	2.536	0.756	0.296	0.278	0.420	0.256
27	0.341	0.260*	0.246	0.212	0.237	0.239*	2.063	0.731	0.285	0.229	0.353	0.234
28	0.333	0.264*	0.236	0.212	0.236	0.234*	1.867	0.717	0.279	0.218	0.267	0.298
29	0.319	0.269*	0.235	0.212		0.230	1.802	0.676	0.276	0.209	0.309	0.344
30	0.311	0.269	0.232	0.212		0.230	1.822	0.639	0.271	0.205	0.546	0.360
31	0.311		0.230	0.210		0.230		0.603		0.201	0.326	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	10.143	10.049	7.619	7.116	6.201	7.287	29.873	29.174	12.265	7.914	6.651	7.350
TOTAL FLOW (cms days)	0.287	0.285	0.216	0.202	0.176	0.206	0.846	0.826	0.347	0.224	0.188	0.208
TOTAL DEPTH (in)	0.663	0.657	0.498	0.465	0.405	0.477	1.953	1.908	0.802	0.517	0.435	0.481
TOTAL DEPTH (cm)	1.685	1.669	1.265	1.182	1.030	1.210	4.962	4.846	2.037	1.314	1.105	1.221

ANNUAL SUMMARY:
Sum of Mean Daily Flow 141.642 cfs = 4.011 cms
Total Depth 9.262 in = 23.525 cm
Maximum Instantaneous Flow 2.920 cfs = 0.083 cms on April 25 at 13.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 208
WATERSHED AREA: 364 ACRES (147 HECTARES)

WATER YEAR 1978
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.300	0.251	0.563	0.661*	0.403	0.511*	5.452	2.727*	1.885	0.756	0.415*	0.296
2	0.262	0.408	3.244	0.630*	0.405	0.534*	4.935	2.727*	1.790	0.761	0.403*	0.292
3	0.245	0.283	2.669	0.599*	0.394	0.565*	4.120*	2.812*	1.710	0.745	0.392*	0.288
4	0.226	0.279	1.828	0.564*	0.394	0.568	3.416*	2.957*	1.612	1.146	0.381*	0.280
5	0.205	0.299	1.415	0.539*	0.394	0.575	2.919*	2.680*	1.526	0.957	0.370*	0.283
6	0.219	0.294	1.201	0.510*	0.492	0.559	2.676*	2.389*	1.443	0.881	0.359*	0.311
7	0.363	0.272*	1.094	0.483*	0.450	0.548	2.510*	2.255*	1.357	1.031	0.345*	0.428
8	0.310	0.256*	0.919	0.470*	0.441	0.564	2.272*	2.263*	1.277	1.167	0.337*	0.379
9	0.383	0.251*	0.840	0.483*	0.441	0.677	2.136*	2.408*	1.241	1.088	0.331*	0.306
10	0.312	0.252	0.779	0.451*	0.441	0.641	2.117*	3.115*	1.327	1.046	0.328*	0.287
11	0.289	0.251	0.769	0.559*	0.441*	0.638	2.422*	3.395*	1.224	0.998	0.327*	0.366
12	0.286	0.251	0.753	0.537*	0.441*	0.629	2.380*	3.130*	1.131	0.956	0.326*	0.503
13	0.266	0.254	0.787	0.511	0.441*	0.628	2.281*	3.046*	1.083	0.912*	0.569*	0.371
14	0.248	0.316	1.212	0.511	0.436	0.652	2.139*	3.185	1.041	0.877*	0.532*	0.346
15	0.237	0.432	1.366	0.511	0.436	0.647	2.082*	3.230*	1.012	0.842*	0.516*	0.329
16	0.226	0.352*	1.430	0.502	0.430*	0.644	2.112*	2.984*	0.965	0.814*	0.559*	0.312
17	0.222	0.314*	1.426	0.494	0.421*	0.648	2.031*	2.734*	0.927	0.784*	0.479	0.305
18	0.217	0.293*	1.309	0.478	0.420	0.701	1.945*	2.464*	0.952	0.753*	0.405	0.317
19	0.202	0.276*	1.150	0.461	0.418	0.770	1.953*	2.386*	0.903	0.723*	0.379	0.316
20	0.196	0.272	1.026*	0.452	0.438	0.865	2.031*	2.407*	0.850	0.691*	0.367	0.297
21	0.196	0.270	0.950*	0.445	0.440	1.067	1.990*	2.395*	0.813	0.663*	0.359	0.286
22	0.196	0.268	0.917	0.444	0.437	1.358	1.884*	2.429*	0.801	0.631*	0.644	0.278
23	0.195	0.269	0.914	0.431	0.440	1.739	1.760*	2.291*	0.787	0.598*	0.423	0.269
24	0.194	0.265	0.914	0.418	0.471	1.988	1.684*	2.232	0.924	0.568*	0.379	0.262
25	0.402	0.628	0.909*	0.407	0.492	2.000	1.853*	2.291*	1.091	0.536*	0.357	0.257
26	0.395	0.841	0.877*	0.404	0.507	2.040	2.270*	2.171*	0.858	0.499*	0.344	0.250
27	0.268	0.514	0.839*	0.395	0.514	2.305	2.668*	2.203*	0.795	0.469*	0.333	0.241
28	0.252	0.456	0.799*	0.370	0.512	3.008	2.721*	2.229*	0.754	0.533*	0.323	0.259
29	0.243	0.646	0.763*	0.368		3.829	2.708*	2.176*	0.802	0.476*	0.303	0.257
30	0.260	0.540	0.729*	0.368		4.636	2.708*	2.036*	0.801	0.446*	0.297	0.252
31	0.255		0.696*	0.368		5.230		1.939		0.427*	0.305	

MONTHLY SUMMARY:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	8.070	10.553	35.088	14.822	12.389	41.762	76.175	79.685	33.681	23.770	12.188	9.219
TOTAL FLOW (cms days)	0.229	0.299	0.994	0.420	0.351	1.183	2.157	2.257	0.954	0.673	0.345	0.261
TOTAL DEPTH (in)	0.528	0.690	2.294	0.969	0.810	2.731	4.981	5.211	2.202	1.554	0.797	0.603
TOTAL DEPTH (cm)	1.340	1.753	5.828	2.462	2.058	6.936	12.652	13.235	5.594	3.948	2.024	1.531

ANNUAL SUMMARY:

Sum of Mean Daily Flow 357.402 cfs = 10.122 cms
Total Depth 23.370 in = 59.360 cm
Maximum Instantaneous Flow 5.480 cfs = 0.155 cms on April 1 at 16.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 209
WATERSHED AREA: 58 ACRES (23 HECTARES)

WATER YEAR 1975
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.010	0.014*	0.011	0.014	0.021	0.038	0.029	0.069	1.210	0.142	0.049	0.049
2	0.008	0.012	0.012	0.014	0.021	0.044	0.029	0.082	1.272	0.130	0.045	0.046
3	0.008	0.011	0.013	0.015	0.021	0.037	0.029	0.105	1.220	0.123	0.042	0.043
4	0.009	0.011	0.017	0.015	0.020	0.036	0.029	0.097	1.032	0.114	0.041	0.040
5	0.010	0.011	0.017	0.015	0.023	0.035	0.028	0.094	0.983	0.107	0.039	0.039
6	0.011	0.013	0.016	0.016	0.024	0.035	0.028	0.095	0.949	0.102	0.038	0.038
7	0.011	0.015	0.020	0.015	0.024	0.032	0.028	0.144	0.820	0.097	0.053	0.036
8	0.012	0.016	0.021	0.015	0.024	0.035	0.028	0.165	0.688	0.089	0.041	0.035
9	0.013	0.012	0.020	0.015	0.022	0.035	0.028	0.210	0.586	0.084	0.038	0.034
10	0.013	0.012	0.020	0.015	0.021	0.034	0.030	0.276	0.527	0.079	0.036	0.034
11	0.018	0.011	0.020	0.014	0.020	0.034	0.033	0.357	0.494	0.074	0.034	0.034
12	0.016	0.015	0.016	0.014	0.019*	0.034	0.040	0.430	0.454	0.072	0.034	0.033
13	0.015	0.017	0.015	0.015	0.018*	0.034	0.049	0.496	0.402	0.086	0.033	0.033
14	0.014	0.013	0.015	0.018	0.018*	0.034	0.062	0.675	0.351	0.082	0.032	0.033
15	0.014	0.012	0.016	0.020	0.018	0.034	0.070	1.043	0.309	0.077	0.032	0.032
16	0.014	0.011	0.020	0.016	0.017	0.034	0.064	1.095	0.269	0.074	0.032	0.054
17	0.014	0.012	0.019	0.127	0.017	0.034	0.059	0.963	0.247	0.070	0.046	0.053
18	0.013	0.016	0.017	0.153	0.017	0.035	0.057	0.905	0.222	0.067	0.061	0.038
19	0.013	0.014	0.016	0.051	0.017	0.038	0.057	0.826	0.235	0.063	0.058	0.036
20	0.013	0.018	0.017	0.040	0.017	0.035	0.058	0.682	0.243	0.060	0.056	0.034
21	0.027	0.019	0.027	0.035	0.017	0.034	0.062	0.582	0.201	0.057	0.043	0.033
22	0.022	0.022	0.019	0.031	0.017	0.034	0.072	0.511	0.183	0.054	0.045	0.032
23	0.019	0.014	0.017	0.035	0.017	0.033	0.076	0.563	0.171	0.050	0.128	0.031
24	0.017	0.018	0.016	0.038	0.018	0.032	0.076	0.588	0.193	0.048	0.101	0.030
25	0.017	0.018	0.016	0.029	0.018	0.033	0.081	0.547	0.167	0.046	0.059	0.030
26	0.017	0.015	0.016	0.027	0.019	0.031	0.073	0.492	0.173	0.046	0.052	0.029
27	0.016	0.014	0.016	0.026	0.019	0.031	0.070	0.479	0.163	0.045	0.050	0.029
28	0.018	0.013	0.016	0.025	0.035	0.030	0.066	0.518	0.154	0.049	0.056	0.029
29	0.017	0.011	0.014	0.023		0.029	0.064	0.636	0.145	0.067	0.050	0.029
30	0.017	0.011	0.014	0.022		0.029	0.068	0.819	0.142	0.054	0.046	0.029
31	0.016*		0.014	0.021		0.029		1.029		0.052	0.050	

MONTHLY SUMMARY:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	0.451	0.420	0.524	0.928	0.556	1.050	1.545	15.569	14.203	2.358	1.520	1.075
TOTAL FLOW (cms days)	0.013	0.012	0.015	0.026	0.016	0.030	0.044	0.441	0.402	0.067	0.043	0.030
TOTAL DEPTH (in)	0.185	0.173	0.215	0.381	0.228	0.431	0.634	6.389	5.828	0.968	0.624	0.441
TOTAL DEPTH (cm)	0.470	0.438	0.547	0.967	0.580	1.094	1.610	16.228	14.804	2.458	1.584	1.121

ANNUAL SUMMARY:
Sum of Mean Daily Flow 40.199 cfs = 1.138 cms
Total Depth 16.497 in = 41.902 cm
Maximum Instantaneous Flow 1.330 cfs = 0.038 cms on June 2 at 3.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 209
WATERSHED AREA: 58 ACRES (23 HECTARES)

WATER YEAR 1976
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.028	0.078	0.253	0.118	0.122	0.083	0.096	0.438	0.246	0.116	0.063	0.043
2	0.026	0.095	0.259	0.118	0.121	0.082	0.094	0.548	0.227	0.111	0.054	0.040
3	0.025	0.115	0.268	0.117	0.121	0.082	0.097	0.707	0.211	0.105	0.092	0.039
4	0.052	0.124	0.286	0.113	0.121	0.082	0.110	1.012	0.200	0.097	0.061	0.039
5	0.033	0.141	0.281	0.109	0.121	0.082	0.141	1.050	0.187	0.095	0.054	0.038
6	0.039	0.143	0.269	0.104	0.121	0.080	0.158	0.955	0.180	0.088	0.046	0.073
7	0.064	0.144	0.311	0.103	0.121	0.077	0.203	0.983	0.172	0.085	0.111	0.046
8	0.043	0.129	0.352	0.101	0.121	0.077	0.289	1.133	0.155	0.082	0.085	0.042
9	0.037	0.117	0.378	0.097	0.103	0.077	0.368	1.270	0.143	0.079	0.068	0.038
10	0.032*	0.111	0.391	0.094	0.100	0.079	0.426	1.413	0.153	0.075	0.060	0.038
11	0.041*	0.102	0.372	0.093	0.094	0.079	0.504	1.391	0.135	0.073	0.055	0.043
12	0.047*	0.094	0.339	0.093	0.094	0.077	0.574	1.100	0.143	0.136	0.055	0.046
13	0.038*	0.091	0.309	0.092	0.093	0.077	0.594	1.045	0.152	0.081	0.053	0.040
14	0.035*	0.092	0.278	0.095	0.093	0.077	0.569	1.094	0.138	0.074	0.052	0.038
15	0.039*	0.105	0.249	0.182	0.092	0.077	0.516	0.892	0.128	0.068	0.076	0.037
16	0.033*	0.092	0.224	0.164	0.090	0.077	0.458	0.801	0.183	0.062	0.068	0.037
17	0.030*	0.082	0.205	0.157	0.088	0.081	0.410	0.745	0.183	0.065	0.058	0.041
18	0.035*	0.075	0.196	0.162	0.087	0.084	0.370	0.655	0.158	0.075	0.063	0.040
19	0.037*	0.073	0.191	0.162	0.086	0.083	0.336	0.604	0.153	0.065	0.055	0.037
20	0.057*	0.072	0.186	0.162	0.085	0.079	0.333	0.551	0.169	0.061	0.052	0.035
21	0.222*	0.072	0.183	0.162	0.085	0.077	0.307	0.506	0.190	0.066	0.051	0.034
22	0.089*	0.072	0.179	0.162	0.085	0.080	0.295	0.482	0.178	0.058	0.055	0.035
23	0.055*	0.067	0.152	0.160	0.085	0.084	0.288	0.471	0.167	0.057	0.061	0.043
24	0.043*	0.099	0.132	0.156	0.085	0.084	0.303	0.449	0.158	0.078	0.050	0.038
25	0.042*	0.078	0.129	0.150	0.085	0.084	0.308	0.447	0.154	0.059	0.077	0.036
26	0.054*	0.075	0.150	0.144	0.085	0.084	0.307	0.379	0.147	0.054	0.065	0.034
27	0.044*	0.073	0.127	0.139	0.085	0.084	0.299	0.357	0.139	0.052	0.055	0.034
28	0.046*	0.071	0.120	0.135	0.085	0.083	0.293	0.337	0.129	0.048	0.051	0.033
29	0.057*	0.069	0.123	0.132	0.085	0.083	0.312	0.299	0.121	0.048	0.049	0.032
30	0.087	0.069	0.123	0.127		0.086	0.351	0.288	0.118	0.047	0.046	0.031
31	0.085		0.118	0.124		0.094		0.273		0.046	0.042	

MONTHLY SUMMARY:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	1.589	2.817	7.132	4.026	2.836	2.513	9.706	22.673	4.918	2.304	1.880	1.178
TOTAL FLOW (cms days)	0.045	0.080	0.202	0.114	0.080	0.071	0.275	0.642	0.139	0.065	0.053	0.033
TOTAL DEPTH (in)	0.652	1.156	2.927	1.652	1.164	1.031	3.983	9.304	2.018	0.946	0.772	0.483
TOTAL DEPTH (cm)	1.656	2.936	7.434	4.197	2.956	2.620	10.117	23.633	5.126	2.402	1.960	1.227

ANNUAL SUMMARY:

Sum of Mean Daily Flow 63.572 cfs = 1.800 cms
Total Depth 26.088 in = 66.264 cm
Maximum Instantaneous Flow 1.820 cfs = 0.052 cms on May 10 at 19.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 209
WATERSHED AREA: 58 ACRES (23 HECTARES)

WATER YEAR 1977
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.030	0.062	0.034	0.029	0.038	0.029*	0.029*	0.307	0.084	0.029	0.015	0.027
2	0.049	0.045	0.033	0.029	0.038	0.029*	0.029*	0.278	0.081	0.036	0.014	0.022
3	0.048	0.041	0.033	0.029	0.038	0.029*	0.029*	0.215	0.077	0.030	0.014	0.020
4	0.037	0.038	0.032	0.029	0.038	0.031*	0.037*	0.191	0.075	0.033	0.013	0.019
5	0.034	0.037	0.030	0.029	0.038	0.031*	0.050*	0.161	0.071	0.032	0.013	0.017
6	0.034	0.036	0.028	0.029	0.038	0.030*	0.073*	0.148	0.068	0.032	0.012	0.016
7	0.032	0.035	0.033	0.029	0.038	0.030*	0.098	0.154	0.067	0.026	0.012	0.014
8	0.031	0.034	0.036	0.029	0.038	0.030*	0.142	0.156	0.087	0.025	0.012	0.014
9	0.030	0.034	0.039	0.029	0.038	0.030*	0.138	0.140	0.067	0.024	0.012	0.013
10	0.040	0.034	0.037	0.029	0.038	0.031*	0.124	0.134	0.066	0.023	0.012	0.013
11	0.053	0.034	0.037	0.029	0.038	0.031*	0.125	0.133	0.068	0.022	0.012	0.013
12	0.037	0.033	0.037	0.029	0.038	0.032*	0.131	0.120	0.072	0.020	0.012	0.013
13	0.034	0.030	0.037	0.029	0.038	0.032*	0.135	0.103	0.073	0.019	0.012	0.013
14	0.032	0.030	0.037	0.029	0.038	0.032*	0.132	0.101	0.066	0.019	0.011	0.013
15	0.030	0.031	0.036	0.031	0.038	0.032*	0.130	0.102	0.060	0.018	0.011	0.026
16	0.030	0.041	0.036	0.034	0.038	0.032*	0.128	0.106	0.057	0.018	0.010	0.048
17	0.030	0.039	0.036	0.043	0.038	0.032*	0.127	0.134	0.053	0.018	0.010	0.044
18	0.030	0.059	0.035	0.065	0.038	0.031*	0.126	0.158	0.051	0.035	0.010	0.033
19	0.030	0.041	0.034	0.055	0.038	0.031*	0.126	0.156	0.050	0.031	0.010	0.028
20	0.029	0.038	0.033	0.045	0.038	0.031*	0.125	0.155	0.050	0.025	0.010	0.052
21	0.029	0.037	0.032	0.044	0.036	0.030*	0.135	0.155	0.050	0.023	0.010	0.047
22	0.029	0.037	0.030	0.044	0.033*	0.030*	0.180	0.147	0.048	0.021	0.011	0.033
23	0.028	0.037	0.030	0.044	0.032*	0.029*	0.249	0.134	0.046	0.020	0.013	0.027
24	0.028	0.039	0.029	0.044	0.032*	0.032*	0.349	0.135	0.044	0.032	0.020	0.025
25	0.045	0.053	0.029	0.043	0.031*	0.031*	0.441	0.135	0.044	0.033	0.034	0.031
26	0.044	0.039	0.029	0.041	0.031*	0.029*	0.425	0.131	0.039	0.034	0.059	0.033
27	0.036	0.026	0.030	0.041	0.030*	0.029*	0.359	0.128	0.030	0.024	0.041	0.027
28	0.034	0.025	0.030	0.041	0.030*	0.029*	0.314	0.128	0.029	0.020	0.027	0.033
29	0.032	0.027	0.029	0.041		0.029*	0.298	0.112	0.029	0.017	0.033	0.042
30	0.031	0.032	0.029	0.039		0.029*	0.275	0.096	0.028	0.017	0.078	0.045
31	0.031		0.029	0.038		0.029*		0.087		0.016	0.035	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	1.066	1.122	1.017	1.142	1.010	0.945	5.059	4.536	1.726	0.767	0.598	0.798
TOTAL FLOW (cms days)	0.030	0.032	0.029	0.032	0.029	0.027	0.143	0.128	0.049	0.022	0.017	0.023
TOTAL DEPTH (in)	0.437	0.460	0.417	0.468	0.414	0.388	2.076	1.862	0.708	0.315	0.245	0.327
TOTAL DEPTH (cm)	1.111	1.169	1.060	1.190	1.052	0.985	5.273	4.728	1.799	0.800	0.623	0.831

ANNUAL SUMMARY:
Sum of Mean Daily Flow 19.785 cfs = 0.560 cms
Total Depth 8.119 in = 20.623 cm
Maximum Instantaneous Flow 0.460 cfs = 0.013 cms on April 25 at 13.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 209
WATERSHED AREA: 58 ACRES (23 HECTARES)

WATER YEAR 1978
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.037	0.032	0.095	0.073	0.050	0.076	0.937	0.470	0.208	0.079	0.043	0.030
2	0.032	0.054	0.445	0.071	0.049	0.076	0.797	0.450	0.195	0.081	0.041	0.029
3	0.028	0.034	0.324	0.070	0.053	0.076	0.653	0.423	0.185	0.078	0.038	0.029
4	0.026	0.032	0.258	0.069	0.052	0.076	0.545	0.380	0.170	0.151	0.036	0.029
5	0.020	0.035	0.213	0.068	0.053	0.082	0.461	0.341	0.156	0.108	0.036	0.029
6	0.021	0.035	0.188	0.061	0.066	0.083	0.416	0.311	0.146	0.097	0.037	0.034
7	0.046	0.032	0.168	0.057	0.058	0.083	0.392	0.283	0.135	0.165	0.036	0.050
8	0.034	0.031	0.143	0.063	0.058	0.088	0.358	0.274	0.127	0.131	0.036	0.040
9	0.048	0.029	0.130	0.063	0.058	0.106	0.338	0.287	0.123	0.120	0.035	0.035
10	0.035	0.028	0.119	0.061	0.057	0.099	0.335	0.354	0.143	0.117	0.034	0.034
11	0.032	0.028	0.122	0.061	0.056	0.099	0.375	0.384	0.127	0.112	0.034	0.058
12	0.031	0.028	0.117	0.062	0.056	0.101	0.357	0.348	0.116	0.106	0.039	0.073
13	0.028	0.032	0.154	0.061	0.056	0.102	0.345	0.340	0.108	0.097	0.060	0.042
14	0.025	0.040	0.195	0.059	0.055	0.102	0.330	0.340	0.102	0.090	0.044	0.039
15	0.023	0.057	0.233	0.058	0.056	0.100	0.328	0.345	0.099	0.090	0.059	0.038*
16	0.021	0.042	0.234	0.057	0.056	0.100	0.323	0.318	0.093	0.085	0.066	0.036*
17	0.021	0.036	0.234	0.055	0.056	0.102	0.305	0.292	0.090	0.081	0.059	0.034*
18	0.019	0.034	0.218	0.055	0.055	0.111	0.292	0.268	0.093	0.075	0.046	0.035
19	0.018	0.034	0.193	0.055	0.056	0.124	0.298	0.262	0.090	0.073	0.043	0.035
20	0.017	0.034	0.171	0.054	0.057	0.145	0.306	0.262	0.084	0.068	0.039	0.032
21	0.017	0.033	0.159	0.052	0.058	0.190	0.298	0.262	0.078	0.063	0.036	0.031
22	0.017	0.031	0.151*	0.051	0.058	0.252	0.280	0.265	0.077	0.060	0.087	0.030
23	0.017	0.030	0.136*	0.051	0.058	0.327	0.271	0.259	0.075	0.058	0.049	0.031
24	0.016	0.027	0.120*	0.051	0.064	0.371	0.262	0.254	0.111	0.057	0.043	0.030
25	0.057	0.118	0.107*	0.050	0.069	0.380	0.294	0.256	0.164	0.053	0.039	0.028
26	0.040	0.083	0.102	0.051	0.071	0.395	0.373	0.261	0.120	0.049	0.037	0.027
27	0.030	0.059	0.096	0.051	0.071	0.448	0.426	0.265	0.109	0.048	0.036	0.026
28	0.027	0.055	0.090	0.051	0.075	0.567	0.430	0.268	0.103	0.063	0.035	0.028
29	0.025	0.091	0.087	0.050		0.716	0.419	0.264	0.125	0.053	0.031	0.029
30	0.030	0.068	0.081	0.049		0.856	0.444	0.243	0.084	0.048	0.030	0.029
31	0.030		0.076	0.050		0.950		0.223		0.045	0.030	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	0.866	1.305	5.158	1.789	1.632	7.382	11.986	9.555	3.634	2.599	1.312	1.051
TOTAL FLOW (cms days)	0.025	0.037	0.146	0.051	0.046	0.209	0.339	0.271	0.103	0.074	0.037	0.030
TOTAL DEPTH (in)	0.355	0.535	2.117	0.734	0.670	3.029	4.919	3.921	1.491	1.067	0.538	0.431
TOTAL DEPTH (cm)	0.903	1.360	5.377	1.864	1.701	7.695	12.494	9.959	3.788	2.709	1.367	1.096

ANNUAL SUMMARY:
Sum of Mean Daily Flow 48.269 cfs = 1.367 cms
Total Depth 19.808 in = 50.313 cm
Maximum Instantaneous Flow 0.980 cfs = 0.028 cms on March 31 at 12.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 209
WATERSHED AREA: 58 ACRES (23 HECTARES)

WATER YEAR 1979
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.029	0.020	0.023	0.019	0.016	0.029	0.076	0.789*	0.149*	0.044	0.019	0.022
2	0.026	0.020	0.024	0.019	0.016	0.029	0.071	0.787*	0.145*	0.046	0.019	0.018
3	0.025	0.020	0.024	0.019	0.016	0.028	0.068	0.759*	0.133*	0.042	0.018	0.017
4	0.024	0.020	0.039	0.019	0.016	0.028	0.064	0.839*	0.122*	0.040	0.018	0.017
5	0.024	0.020	0.030	0.017	0.015	0.031	0.073	0.934*	0.115*	0.040	0.018	0.016
6	0.024	0.020	0.028	0.016	0.016	0.062	0.082	0.796*	0.121*	0.037	0.017	0.015
7	0.024	0.020	0.026	0.016	0.015	0.073	0.103	0.655*	0.085	0.036	0.017	0.015
8	0.024	0.093	0.025	0.015	0.014	0.053	0.103	0.574*	0.073	0.035	0.016	0.014
9	0.023	0.038	0.024	0.015	0.014	0.044	0.112	0.517*	0.073	0.034	0.014	0.015
10	0.023	0.032	0.019	0.015	0.016	0.040	0.111	0.519*	0.066	0.034	0.015	0.020
11	0.023	0.030	0.018	0.016	0.023	0.040	0.104*	0.519*	0.062	0.033	0.015	0.015
12	0.022	0.030	0.018	0.016	0.044	0.040	0.092*	0.518*	0.060	0.032	0.015	0.013
13	0.022	0.029	0.018	0.016	0.088	0.040	0.084*	0.524*	0.057	0.030	0.017	0.013
14	0.022	0.027	0.018	0.016	0.048	0.041	0.078*	0.533*	0.055	0.029	0.018	0.013
15	0.022	0.027	0.018	0.016	0.034	0.047	0.076*	0.547*	0.053	0.028	0.026	0.013
16	0.022	0.028	0.018	0.016	0.031	0.056	0.089*	0.527*	0.050	0.027	0.019	0.012
17	0.022	0.028	0.018	0.016	0.030	0.055	0.161*	0.471*	0.049	0.026	0.018	0.012
18	0.021	0.026	0.018	0.016	0.030	0.052	0.178*	0.431*	0.052	0.025	0.024	0.011
19	0.021	0.024	0.018	0.015	0.030	0.051	0.168*	0.386*	0.062	0.025	0.027	0.011
20	0.020	0.025	0.017	0.016	0.030	0.052	0.147*	0.352*	0.055	0.024	0.019	0.011
21	0.020	0.024	0.017	0.016	0.029	0.052	0.134*	0.328*	0.051	0.024	0.020	0.011
22	0.020	0.024	0.017	0.016	0.028	0.052	0.142*	0.300*	0.092	0.029	0.020	0.011
23	0.020	0.024	0.018	0.015	0.028	0.053	0.166*	0.276*	0.058	0.026	0.051	0.012
24	0.020	0.024	0.018	0.015	0.028	0.058	0.205*	0.292*	0.051	0.024	0.031	0.011
25	0.020	0.024	0.018	0.015	0.028	0.063	0.241*	0.245*	0.047	0.024	0.022	0.011
26	0.020	0.024	0.018	0.015	0.028	0.063	0.289*	0.225*	0.045	0.023	0.022	0.012
27	0.020	0.024	0.018	0.016	0.029	0.071	0.388*	0.210*	0.042	0.022	0.021	0.011
28	0.020	0.024	0.018	0.015	0.028	0.090	0.529*	0.200*	0.040	0.022	0.019	0.011
29	0.020	0.023	0.018	0.016		0.089	0.673*	0.184*	0.039	0.022	0.026	0.011
30	0.020	0.024	0.018	0.016		0.085	0.760*	0.168*	0.040	0.022	0.050	0.011
31	0.020		0.018	0.016		0.080		0.154*		0.020	0.047	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	0.680	0.815	0.637	0.495	0.767	1.644	5.564	14.560	2.141	0.926	0.698	0.401
TOTAL FLOW (cms days)	0.019	0.023	0.018	0.014	0.022	0.047	0.158	0.412	0.061	0.026	0.020	0.011
TOTAL DEPTH (in)	0.279	0.335	0.262	0.203	0.315	0.674	2.283	5.975	0.879	0.380	0.286	0.165
TOTAL DEPTH (cm)	0.708	0.850	0.664	0.515	0.799	1.713	5.800	15.177	2.232	0.965	0.727	0.418

ANNUAL SUMMARY:

Sum of Mean Daily Flow	29.328 cfs =	0.831 cms	
Total Depth	12.035 in =	30.570 cm	
Maximum Instantaneous Flow	4.990 cfs =	0.141 cms	on May 16 at 12.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 209
WATERSHED AREA: 58 ACRES (23 HECTARES)

WATER YEAR 1980
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.011	0.017	0.017	0.028	0.025	0.054	0.038	0.285	0.281	0.123	0.045*	0.026
2	0.011	0.016	0.039	0.027	0.015	0.052	0.037	0.377	0.286	0.184	0.045*	0.044
3	0.011	0.020	0.042	0.027	0.033	0.052	0.037	0.346	0.266	0.172	0.044*	0.031
4	0.011	0.024	0.056	0.025	0.024	0.060	0.036	0.311	0.278	0.165	0.043*	0.030
5	0.011	0.027	0.041	0.024	0.022	0.055	0.040	0.284	0.260	0.159	0.042*	0.030
6	0.011	0.023	0.034	0.025	0.021	0.054	0.041	0.263	0.258	0.157	0.041*	0.031
7	0.011	0.020	0.047	0.020	0.021	0.055	0.038	0.248	0.235	0.139	0.041*	0.031
8	0.011	0.019	0.044	0.017	0.020	0.053	0.037	0.199	0.213	0.121	0.040*	0.031
9	0.010	0.017	0.045	0.017	0.020	0.050	0.044	0.177	0.201	0.164	0.039*	0.031
10	0.011	0.016	0.053	0.017	0.020	0.053	0.042	0.160	0.197	0.131	0.038*	0.040
11	0.010	0.017	0.036	0.017	0.020	0.053	0.045	0.140	0.216	0.117	0.037*	0.046
12	0.010	0.016	0.033	0.036	0.021	0.050	0.051	0.128	0.222	0.108	0.036*	0.031
13	0.010	0.017	0.031	0.050	0.022	0.049	0.074	0.118	0.206	0.101	0.034*	0.047
14	0.010	0.017	0.031	0.060	0.022	0.047	0.095	0.110	0.221	0.122	0.030*	0.036
15	0.026	0.016	0.033	0.042	0.021	0.046	0.116	0.132	0.225	0.101	0.029*	0.028
16	0.017	0.017	0.032	0.035	0.021	0.045	0.131	0.116	0.213	0.091	0.030*	0.025
17	0.025	0.036	0.072	0.032	0.022	0.044	0.210	0.107	0.206	0.086	0.030*	0.025
18	0.034	0.024	0.058	0.031	0.033	0.043	0.310	0.099	0.198	0.082	0.044*	0.044
19	0.053	0.020	0.048	0.028	0.044	0.043	0.381	0.092	0.181	0.075	0.036	0.037
20	0.028	0.020	0.046	0.026	0.044	0.043	0.482	0.083	0.169	0.070	0.030	0.105
21	0.028	0.021	0.042	0.026	0.035	0.044	0.540	0.089	0.157	0.065	0.030	0.077
22	0.031	0.021	0.039	0.025	0.032	0.043	0.566	0.095	0.153	0.059	0.030	0.045
23	0.032	0.021	0.036	0.024	0.031	0.041	0.589	0.103	0.141	0.056	0.030	0.037
24	0.024	0.020	0.035	0.024	0.031	0.042	0.612	0.112	0.131	0.052	0.027	0.036
25	0.027	0.019	0.035	0.023	0.031	0.040	0.520	0.173	0.121	0.051*	0.021	0.033
26	0.026	0.019	0.035	0.023	0.035	0.040	0.494	0.235	0.133	0.050*	0.020	0.031
27	0.023	0.018	0.033	0.024	0.051	0.040	0.470	0.272	0.125	0.049*	0.020	0.031
28	0.022	0.018	0.031	0.024	0.069	0.039	0.438	0.287	0.107	0.048*	0.020	0.031
29	0.023	0.018	0.030	0.025	0.059	0.039	0.385	0.286	0.098	0.047*	0.020	0.031
30	0.020	0.017	0.030	0.025		0.038	0.323	0.293	0.093	0.047*	0.020	0.024
31	0.019		0.030	0.025		0.038		0.265		0.046*	0.032	

MONTHLY SUMMARY:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	0.604	0.590	1.214	0.851	0.864	1.443	7.223	5.978	5.789	3.036	1.022	1.125
TOTAL FLOW (cms days)	0.017	0.017	0.034	0.024	0.024	0.041	0.205	0.169	0.164	0.086	0.029	0.032
TOTAL DEPTH (in)	0.248	0.242	0.498	0.349	0.355	0.592	2.964	2.453	2.376	1.246	0.420	0.462
TOTAL DEPTH (cm)	0.630	0.615	1.265	0.887	0.901	1.504	7.529	6.231	6.034	3.164	1.066	1.173

ANNUAL SUMMARY:
Sum of Mean Daily Flow 29.739 cfs = 0.842 cms
Total Depth 12.204 in = 30.998 cm
Maximum Instantaneous Flow 1.270 cfs = 0.036 cms on May 2 at 14.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 209
WATERSHED AREA: 58 ACRES (23 HECTARES)

WATER YEAR 1981
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.021	0.036	0.038	0.191	0.052	0.120	0.160	0.136	0.132	0.154	0.041	0.028*
2	0.021	0.035	0.039	0.168	0.046	0.117	0.148	0.130	0.122	0.141	0.040	0.034
3	0.021	0.036	0.034	0.151	0.046	0.114	0.146	0.122	0.115	0.129	0.040	0.027
4	0.021	0.036	0.037	0.140	0.040	0.112	0.138	0.117	0.120	0.120	0.038	0.023
5	0.021	0.023	0.032	0.129	0.040	0.103	0.140	0.118	0.135	0.113	0.038	0.023
6	0.021	0.041	0.031	0.118	0.040	0.102	0.132	0.107	0.168	0.153	0.038	0.023
7	0.020	0.081	0.029	0.108	0.040	0.101	0.121	0.099	0.165	0.162	0.038	0.023
8	0.020	0.047	0.028	0.093	0.040	0.098	0.116	0.094	0.312	0.118	0.037	0.023
9	0.019	0.048	0.027	0.089	0.040	0.097	0.114	0.089	0.374	0.107	0.037	0.023
10	0.018	0.044	0.026	0.085	0.038	0.096	0.110	0.089	0.405	0.100	0.037	0.023
11	0.018	0.038	0.025	0.080	0.037	0.096	0.109	0.102	0.386	0.095	0.037	0.021
12	0.024	0.034	0.024	0.074	0.047	0.098	0.105	0.089	0.435	0.091	0.035*	0.020
13	0.032	0.029	0.024	0.070	0.058	0.102	0.099	0.082	0.455	0.086	0.033*	0.020
14	0.032	0.027	0.024	0.067	0.089	0.104	0.103	0.081	0.490	0.080	0.031*	0.020
15	0.032	0.027	0.030	0.064	0.064	0.109	0.125	0.096	0.442	0.077	0.029*	0.020
16	0.032	0.027	0.036	0.061	0.161	0.119	0.128	0.085	0.496	0.074	0.027*	0.020
17	0.032	0.028	0.035	0.059	0.127	0.116	0.137	0.083	0.479	0.070	0.026*	0.020
18	0.032	0.028	0.035	0.058	0.132	0.114	0.162	0.077	0.479	0.069	0.025*	0.020
19	0.032	0.028	0.034	0.058	0.154	0.117	0.187	0.075	0.526	0.067	0.023*	0.031
20	0.032	0.027	0.034	0.058	0.145	0.118	0.197	0.074	0.523	0.062	0.022*	0.030
21	0.032	0.032	0.050	0.058	0.145	0.114	0.202	0.149	0.491	0.061	0.021*	0.025
22	0.033	0.044	0.128	0.058	0.145	0.117	0.208	0.122	0.439	0.059	0.021*	0.025
23	0.033	0.041	0.074	0.099	0.145	0.115	0.205	0.169	0.385	0.056	0.021*	0.022
24	0.033	0.042	0.090	0.075	0.145	0.113	0.211	0.159	0.327	0.054	0.021*	0.019
25	0.033	0.042	0.287	0.064	0.136	0.149	0.194	0.186	0.283	0.059	0.021*	0.032
26	0.035	0.042	0.492	0.061	0.131	0.146	0.182	0.170	0.249	0.056	0.021*	0.030
27	0.035	0.043	0.440	0.059	0.124	0.158	0.171	0.166	0.224	0.050	0.021*	0.052
28	0.035	0.043	0.351	0.057	0.121	0.158	0.168	0.160	0.202	0.047	0.021*	0.055
29	0.035	0.041	0.286	0.057		0.167	0.155	0.153	0.182	0.045	0.021*	0.033
30	0.035	0.040	0.262	0.056		0.164	0.145	0.168	0.166	0.043	0.063*	0.029
31	0.036		0.216	0.056		0.169		0.153		0.043	0.028*	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	0.875	1.127	3.297	2.621	2.527	3.722	4.515	3.699	9.708	2.637	0.950	0.792
TOTAL FLOW (cms days)	0.025	0.032	0.093	0.074	0.072	0.105	0.128	0.105	0.275	0.075	0.027	0.022
TOTAL DEPTH (in)	0.359	0.463	1.353	1.075	1.037	1.527	1.853	1.518	3.984	1.082	0.390	0.325
TOTAL DEPTH (cm)	0.913	1.175	3.437	2.732	2.634	3.880	4.707	3.856	10.119	2.748	0.990	0.825

ANNUAL SUMMARY:
Sum of Mean Daily Flow 36.471 cfs = 1.033 cms
Total Depth 14.967 in = 38.015 cm
Maximum Instantaneous Flow 0.700 cfs = 0.020 cms on June 16 at 18.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 209
WATERSHED AREA: 58 ACRES (23 HECTARES)

WATER YEAR 1982
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.028	0.029	0.031	0.032	0.036	0.088	0.089*	0.763*	0.697	0.146	0.097	0.030
2	0.028	0.028	0.044	0.031	0.036	0.088	0.089*	0.790*	0.695	0.113	0.109	0.029
3	0.027	0.025	0.043	0.029	0.036	0.084	0.088*	0.710*	0.578	0.108	0.091	0.021
4	0.026	0.021	0.033	0.028	0.036	0.080	0.084*	0.635*	0.413	0.106	0.048	0.019
5	0.025	0.021	0.041	0.028	0.036	0.076	0.079*	0.551	0.375	0.111	0.044	0.018
6	0.024	0.021	0.062	0.028	0.036	0.075	0.077*	0.483	0.348	0.098	0.043	0.017
7	0.028	0.021	0.046	0.028	0.037	0.075	0.074*	0.488	0.355	0.103	0.041	0.017
8	0.029	0.021	0.041	0.026	0.039	0.075	0.070*	0.488	0.310	0.101	0.043	0.016
9	0.049	0.021	0.043	0.024	0.041	0.083	0.067*	0.490	0.289	0.103	0.043	0.017
10	0.056	0.021	0.050	0.024	0.042	0.088	0.065*	0.482	0.281	0.094	0.040	0.064
11	0.061	0.021	0.041	0.024	0.045	0.093	0.084*	0.478	0.273	0.088	0.041	0.029
12	0.046	0.041	0.037	0.028	0.053	0.096	0.141*	0.478	0.266	0.083	0.043	0.041
13	0.036	0.033	0.036	0.026	0.059	0.097	0.199*	0.535	0.251	0.095	0.039	0.027
14	0.033	0.033	0.036	0.025	0.104	0.100	0.258*	0.659	0.232	0.095	0.039	0.022
15	0.030	0.029	0.033	0.027	0.074	0.104	0.266*	0.775	0.200	0.081	0.037	0.021
16	0.029	0.030	0.032	0.027	0.136	0.105	0.257*	0.829	0.182	0.089	0.035	0.021
17	0.028	0.048	0.032	0.027	0.132	0.103	0.235*	0.877	0.164	0.082	0.035	0.020
18	0.028	0.038	0.032	0.027	0.125	0.102	0.212*	0.932	0.151	0.081	0.035	0.019
19	0.026	0.033	0.098	0.027	0.141	0.099	0.194*	0.842	0.142	0.084	0.034	0.018
20	0.024	0.031	0.056	0.027	0.152	0.098	0.175*	0.765	0.132	0.082	0.033	0.021
21	0.023	0.045	0.047	0.027	0.162	0.093	0.164*	0.766	0.125	0.083	0.045	0.019
22	0.023	0.042	0.042	0.027	0.159	0.089	0.183*	0.827	0.125	0.083	0.034	0.018
23	0.022	0.036	0.041	0.027	0.147	0.087	0.303*	0.835	0.121	0.080	0.032	0.018
24	0.023	0.034	0.040	0.042	0.135	0.087	0.453*	0.804	0.110	0.081	0.031	0.018
25	0.023	0.032	0.037	0.040	0.122	0.086	0.532*	0.831	0.105	0.083	0.029	0.019
26	0.043	0.032	0.035	0.039	0.110	0.086	0.555*	0.836	0.101	0.094	0.029	0.039
27	0.033	0.032	0.034	0.038	0.097	0.086	0.587*	0.805	0.098	0.103	0.029	0.045
28	0.029	0.032	0.033	0.038	0.091	0.086	0.682*	0.811	0.138	0.102	0.029	0.060
29	0.029	0.032	0.032	0.037		0.086	0.725*	0.784	0.118	0.101	0.029	0.036
30	0.029	0.031	0.031	0.037		0.087	0.718*	0.711	0.101	0.100	0.041	0.028
31	0.029		0.031	0.036		0.088		0.698		0.102	0.033	

MONTHLY SUMMARY:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	0.966	0.912	1.268	0.926	2.418	2.769	7.705	21.755	7.478	2.952	1.331	0.785
TOTAL FLOW (cms days)	0.027	0.026	0.036	0.026	0.068	0.078	0.218	0.616	0.212	0.084	0.038	0.022
TOTAL DEPTH (in)	0.396	0.374	0.520	0.380	0.992	1.136	3.162	8.928	3.069	1.212	0.546	0.322
TOTAL DEPTH (cm)	1.007	0.950	1.322	0.965	2.521	2.887	8.031	22.677	7.794	3.077	1.387	0.818

ANNUAL SUMMARY:
Sum of Mean Daily Flow 51.265 cfs = 1.452 cms
Total Depth 21.038 in = 53.436 cm
Maximum Instantaneous Flow 0.940 cfs = 0.027 cms on May 17 at 22.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 209
WATERSHED AREA: 58 ACRES (23 HECTARES)

WATER YEAR 1983
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.034	0.045	0.029	0.026	0.040	0.104	0.109	0.167	0.072	0.074	0.029	0.036
2	0.033	0.040	0.028	0.026	0.038	0.119	0.109	0.160	0.071	0.071	0.027	0.030
3	0.064	0.036	0.031	0.026	0.038	0.125	0.106	0.146	0.068	0.057	0.023	0.020
4	0.042	0.036	0.070	0.026	0.037	0.138	0.103	0.136	0.064	0.049	0.020	0.019
5	0.040	0.039	0.042	0.077	0.035	0.152	0.100	0.165	0.061	0.044	0.020	0.017
6	0.038	0.047	0.040	0.058	0.033	0.163	0.101	0.152	0.059	0.042	0.020	0.015
7	0.056	0.039	0.037	0.087	0.033	0.175	0.099	0.130	0.057	0.038	0.022	0.013
8	0.055	0.036	0.035	0.076	0.033	0.185	0.097	0.139	0.060	0.036	0.024	0.012
9	0.046	0.036	0.033	0.066	0.032	0.203	0.096	0.127	0.055	0.038	0.046	0.014
10	0.041	0.036	0.032	0.060	0.031	0.235	0.094	0.130	0.062	0.057	0.045	0.048
11	0.040	0.035	0.031	0.058	0.033	0.272	0.092	0.120	0.059	0.040	0.044	0.055
12	0.038	0.030	0.031	0.056	0.038	0.289	0.091	0.116	0.074	0.037	0.030	0.023
13	0.035	0.032	0.030	0.053	0.039	0.299	0.090	0.113	0.059	0.035	0.026	0.018
14	0.034	0.029	0.029	0.051	0.039	0.280	0.093	0.108	0.051	0.075	0.034	0.018
15	0.033	0.029	0.029	0.049	0.038	0.258	0.095	0.127	0.059	0.047	0.031	0.015
16	0.033	0.029	0.037	0.048	0.039	0.235	0.097	0.124	0.049	0.042	0.027	0.015
17	0.035	0.035	0.042	0.046	0.057	0.216	0.110	0.125	0.058	0.038	0.023	0.015
18	0.036	0.038	0.037	0.046	0.106	0.198	0.127	0.152	0.071	0.036	0.021	0.027
19	0.035	0.037	0.037	0.043	0.075	0.176	0.149	0.146	0.057	0.034	0.019	0.036
20	0.036	0.035	0.036	0.039	0.068	0.158	0.172	0.140	0.052	0.047	0.019	0.027
21	0.039	0.034	0.036	0.039	0.068	0.149	0.188	0.138	0.047	0.041	0.018	0.026
22	0.039	0.031	0.037	0.039	0.076	0.140	0.209	0.133	0.044	0.037	0.020	0.025
23	0.036	0.027	0.037	0.039	0.077	0.134	0.242	0.125	0.043	0.038	0.025	0.023
24	0.036	0.026	0.036	0.039	0.088	0.122	0.298	0.116	0.042	0.055	0.022	0.021
25	0.035	0.026	0.035	0.037	0.094	0.119	0.262	0.108	0.040	0.041	0.021	0.021
26	0.047	0.026	0.034	0.037	0.098	0.112	0.231	0.103	0.038	0.035	0.020	0.020
27	0.049	0.026	0.033	0.043	0.100	0.109	0.211	0.097	0.047	0.033	0.021	0.017
28	0.042	0.029	0.033	0.045	0.100	0.103	0.196	0.090	0.045	0.032	0.019	0.016
29	0.052	0.032	0.032	0.042		0.107	0.184	0.083	0.048	0.031	0.016	0.014
30	0.053	0.032	0.032	0.042		0.128	0.177	0.076	0.044	0.029	0.016	0.017
31	0.045		0.029	0.041		0.111		0.073		0.029	0.019	

MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	1.275	1.003	1.090	1.457	1.582	5.313	4.326	3.865	1.656	1.336	0.764	0.673
TOTAL FLOW (cms days)	0.036	0.028	0.031	0.041	0.045	0.150	0.123	0.109	0.047	0.038	0.022	0.019
TOTAL DEPTH (in)	0.523	0.411	0.447	0.598	0.649	2.180	1.775	1.586	0.680	0.548	0.314	0.276
TOTAL DEPTH (cm)	1.329	1.045	1.136	1.518	1.649	5.538	4.509	4.029	1.726	1.392	0.797	0.701

ANNUAL SUMMARY:
Sum of Mean Daily Flow 24.340 cfs = 0.689 cms
Total Depth 9.988 in = 25.370 cm
Maximum Instantaneous Flow 0.360 cfs = 0.010 cms on April 24 at 2.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 209
WATERSHED AREA: 58 ACRES (23 HECTARES)

WATER YEAR 1984
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.017	0.017	0.021	0.010	0.047	0.039	0.101	0.224	0.580	0.105	0.130	0.041
2	0.017	0.027	0.020	0.017	0.043	0.043	0.099	0.251	0.501	0.102	0.131	0.033
3	0.017	0.023	0.020	0.111	0.040	0.041	0.097	0.244	0.458	0.098	0.128	0.032
4	0.016	0.038	0.019	0.089	0.040	0.040	0.099	0.243	0.448	0.095	0.124	0.028
5	0.015	0.026	0.019	0.076	0.040	0.038	0.118	0.244	0.423	0.093	0.112	0.026
6	0.015	0.050	0.019	0.074	0.040	0.038	0.126	0.240	0.412	0.092	0.112	0.042
7	0.015	0.034	0.020	0.064	0.040	0.038	0.124	0.234	0.451	0.090	0.108	0.033
8	0.016	0.029	0.021	0.059	0.040	0.038	0.143	0.249	0.435	0.086	0.104	0.045
9	0.034	0.025	0.020	0.055	0.039	0.040	0.145	0.385	0.429	0.085	0.101	0.034
10	0.024	0.024	0.034	0.051	0.039	0.049	0.146	0.431	0.407	0.081	0.101	0.031
11	0.020	0.040	0.030	0.049	0.038	0.055	0.146	0.484	0.432	0.072	0.099	0.029
12	0.016	0.041	0.028	0.046	0.040	0.057	0.145	0.616	0.388	0.067	0.089	0.027
13	0.016	0.038	0.026	0.044	0.069	0.055	0.143	0.783	0.367	0.063	0.082	0.027
14	0.017	0.033	0.026	0.041	0.055	0.080	0.150	1.056	0.303	0.062	0.081	0.026
15	0.016	0.033	0.022	0.039	0.052	0.077	0.209	1.077	0.261	0.060	0.078	0.025
16	0.016	0.035	0.021	0.036	0.049	0.083	0.353	0.837	0.234	0.058	0.074	0.024
17	0.025	0.039	0.021	0.035	0.047	0.086	0.616	0.728	0.211	0.057	0.093	0.023
18	0.029	0.034	0.021	0.033	0.047	0.085	0.744	0.695	0.202	0.060	0.069	0.022
19	0.022	0.032	0.020	0.030	0.047	0.101	0.709	0.745	0.184	0.059	0.056	0.022
20	0.020	0.030	0.021	0.026	0.046	0.159	0.593	0.919	0.181	0.058	0.057	0.071
21	0.019	0.028	0.021	0.022	0.044	0.165	0.492	0.855	0.223	0.058	0.060	0.051
22	0.034	0.022	0.015	0.021	0.043	0.169	0.453	0.735	0.177	0.057	0.061	0.036
23	0.038	0.021	0.012	0.022	0.042	0.168	0.465	0.850	0.157	0.057	0.060	0.046
24	0.026	0.026	0.012	0.082	0.037	0.163	0.466	0.800	0.146	0.061	0.060	0.040
25	0.023	0.030	0.012	0.098	0.037	0.149	0.427	0.700	0.156	0.063	0.058	0.034
26	0.022	0.028	0.011	0.058	0.037	0.141	0.368	0.716	0.138	0.104	0.060	0.032
27	0.021	0.026	0.010	0.054	0.036	0.138	0.317	0.718	0.123	0.141	0.060	0.030
28	0.018	0.025	0.010	0.053	0.035	0.125	0.275	0.729	0.114	0.174	0.051	0.029
29	0.017	0.024	0.010	0.051	0.036	0.112	0.248	0.791	0.113	0.151	0.027	0.029
30	0.017	0.022	0.010	0.050		0.108	0.232	0.942	0.110	0.138	0.036	0.028
31	0.017		0.010	0.049		0.106		0.764		0.131	0.058	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	0.634	0.899	0.583	1.543	1.247	2.782	8.747	19.285	8.764	2.674	2.516	0.995
TOTAL FLOW (cms days)	0.018	0.025	0.016	0.044	0.035	0.079	0.248	0.546	0.248	0.076	0.071	0.028
TOTAL DEPTH (in)	0.260	0.369	0.239	0.633	0.512	1.142	3.590	7.914	3.597	1.097	1.033	0.408
TOTAL DEPTH (cm)	0.661	0.937	0.607	1.608	1.300	2.900	9.118	20.101	9.135	2.787	2.623	1.037

ANNUAL SUMMARY:
Sum of Mean Daily Flow 50.667 cfs = 1.435 cms
Total Depth 20.793 in = 52.813 cm
Maximum Instantaneous Flow 1.390 cfs = 0.039 cms on May 30 at 14.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 210
WATERSHED AREA: 161 ACRES (65 HECTARES)

WATER YEAR 1975
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.064	0.088	0.056*	0.039	0.071*	0.129	0.087	0.206	4.166	0.475	0.182	0.136
2	0.063	0.079	0.049*	0.039	0.074*	0.159	0.086	0.252	4.373	0.433	0.170	0.125
3	0.064	0.075	0.042*	0.039	0.077*	0.132	0.085	0.335	4.248	0.403	0.159	0.115
4	0.067	0.074	0.046	0.040	0.080*	0.123	0.085	0.314	3.612	0.376	0.153	0.109
5	0.067	0.075	0.044	0.040	0.082*	0.117	0.084	0.307	3.348	0.351	0.147	0.104
6	0.069	0.084	0.041	0.041	0.082	0.113	0.084	0.289	3.279	0.338	0.142	0.099
7	0.068	0.092	0.041	0.041	0.082	0.109	0.084	0.354	2.926	0.335	0.208*	0.095
8	0.062	0.083	0.038	0.040	0.082	0.109	0.083	0.410	2.384	0.316	0.147	0.092
9	0.061	0.080	0.038	0.040	0.082	0.116	0.082	0.543	2.057	0.303	0.140	0.089
10	0.061	0.080	0.039	0.040	0.082	0.112	0.088	0.850	1.810	0.286	0.134	0.088
11	0.075	0.080	0.042	0.038	0.081	0.105	0.100	1.306	1.657	0.310	0.130	0.087
12	0.067	0.100	0.041	0.038	0.080	0.101	0.121	1.452	1.497	0.270	0.128	0.085
13	0.065	0.086	0.038	0.042	0.082	0.099	0.144	1.606	1.338	0.306	0.125	0.084
14	0.064	0.078	0.039	0.050	0.083	0.098	0.179	2.411	1.191	0.292	0.121	0.081
15	0.062	0.074	0.039	0.049	0.081	0.097	0.227	3.593	1.047	0.269	0.117	0.082
16	0.061	0.073	0.054	0.044	0.080	0.097	0.214	3.587	0.938	0.257	0.118	0.136
17	0.059	0.081	0.046	0.405	0.078	0.095	0.195	3.191	0.872	0.241	0.156	0.140
18	0.059	0.086	0.042	0.378	0.077	0.099	0.185	2.991	0.790	0.230	0.202	0.101
19	0.059	0.083	0.042	0.158	0.077	0.103	0.186	2.553	0.800	0.217	0.191	0.090
20	0.063	0.098	0.049	0.130	0.077	0.098	0.186	1.924	0.808	0.210	0.187	0.085
21	0.150	0.115	0.062	0.113	0.076	0.097	0.197	1.622	0.680	0.206	0.151	0.081
22	0.088	0.092	0.047	0.102	0.075	0.096	0.235	1.445	0.621	0.198	0.159	0.078
23	0.079	0.085	0.044	0.125	0.075	0.094	0.258	1.691	0.578	0.189	0.392	0.076
24	0.074	0.095	0.043	0.109	0.080	0.094	0.261	1.859	0.608	0.185	0.312	0.074
25	0.071	0.091	0.042	0.092	0.079	0.093	0.274	1.622	0.559	0.179	0.208	0.073
26	0.068	0.082	0.041	0.086	0.078	0.091	0.244	1.424	0.558	0.175	0.178	0.073
27	0.070	0.081	0.041	0.081	0.078	0.089	0.229	1.398	0.563	0.170	0.169	0.072
28	0.074	0.078*	0.041	0.078	0.118	0.088	0.210	1.601	0.522	0.173	0.189	0.071
29	0.071	0.070*	0.040	0.075		0.088	0.202	2.207	0.485	0.257	0.137	0.070
30	0.069	0.062*	0.039	0.072		0.088	0.204	3.036	0.477	0.199	0.127	0.074
31	0.074		0.039	0.071		0.088		3.665		0.190	0.139	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	2.164	2.502	1.343	2.735	2.248	3.215	4.896	50.041	48.792	8.337	5.216	2.764
TOTAL FLOW (cms days)	0.061	0.071	0.038	0.077	0.064	0.091	0.139	1.417	1.382	0.236	0.148	0.078
TOTAL DEPTH (in)	0.320	0.370	0.199	0.404	0.332	0.475	0.724	7.398	7.213	1.233	0.771	0.409
TOTAL DEPTH (cm)	0.813	0.939	0.504	1.027	0.844	1.207	1.838	18.790	18.322	3.131	1.959	1.038

ANNUAL SUMMARY:
Sum of Mean Daily Flow 134.253 cfs = 3.802 cms
Total Depth 19.847 in = 50.413 cm
Maximum Instantaneous Flow 4.760 cfs = 0.135 cms on June 3 at 6.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 210
WATERSHED AREA: 161 ACRES (65 HECTARES)

WATER YEAR 1976
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.069	0.211	0.650*	2.447	0.229	0.222	0.251	1.540	0.723	0.360	0.171	0.100
2	0.064	0.256	0.823	0.168	0.226	0.222	0.239	2.049	0.658	0.339	0.166	0.096
3	0.064	0.315	0.782	0.168	0.226	0.222	0.257	2.513	0.631*	0.320	0.194	0.100
4	0.131	0.354	0.833	0.195	0.222	0.222	0.300	3.353	0.599*	0.305	0.166	0.103
5	0.086	0.393	0.786	0.215	0.227	0.222	0.394	3.383	0.560*	0.294	0.154	0.101
6	0.102	0.398	0.723	0.216	0.241	0.222	0.493	3.137	0.539*	0.276	0.143	0.191
7	0.162	0.394	0.831	0.216	0.253	0.222	0.641	3.299	0.516	0.269	0.320	0.124
8	0.112	0.348	0.965	0.213	0.262	0.222	0.929	3.822	0.497	0.311	0.319	0.113
9	0.097	0.306	1.051	0.196	0.266	0.219	1.273	4.287	0.458	0.257	0.227	0.105
10	0.090	0.288	1.041	0.188	0.270	0.226	1.377	4.715	0.486	0.247	0.196	0.101
11	0.136	0.264	0.934	0.183	0.274	0.228	1.550	4.821	0.433	0.238	0.178	0.118
12	0.153	0.247	0.850	0.183	0.276	0.219	1.816	4.013	0.453	0.402	0.170	0.121
13	0.127	0.241	0.761	0.182	0.275	0.214	1.827	3.892	0.470	0.264	0.165	0.106
14	0.115	0.248	0.681	0.180	0.267	0.211	1.711	4.007	0.428	0.239	0.165	0.099
15	0.125	0.276	0.612	0.331	0.257	0.209	1.565	3.384	0.397	0.224	0.227	0.097
16	0.109	0.246	0.555	0.330	0.241	0.213	1.368	3.060	0.550	0.210	0.212	0.109
17	0.100	0.224*	0.509	0.314	0.222	0.226	1.204	2.816	0.586	0.212	0.154	0.114
18	0.118	0.196*	0.483	0.326	0.211	0.228	1.076	2.437	0.525	0.239	0.146	0.110
19	0.119	0.183*	0.479	0.326	0.207	0.220	0.963	2.155	0.507	0.212	0.139	0.101
20	0.157	0.177*	0.476	0.326	0.200	0.210	0.947	1.944	0.547	0.198	0.137	0.095
21	0.455	0.177*	0.468	0.320	0.197	0.209	0.885	1.746	0.581	0.214	0.131	0.092
22	0.270	0.176*	0.411	0.314	0.197	0.215	0.847	1.611	0.549	0.182	0.136	0.096
23	0.217	0.171*	0.368	0.311	0.191	0.219	0.839	1.543	0.513	0.175	0.151	0.117
24	0.192	0.214*	0.371	0.300	0.178	0.216	0.911	1.448	0.497	0.241	0.126	0.101
25	0.180	0.184*	0.353	0.288	0.190	0.218	0.942	1.446	0.492	0.187	0.197	0.096
26	0.182	0.181*	0.404	0.277	0.221	0.218	0.955	1.183	0.465	0.172	0.165	0.092
27	0.164	0.175*	0.354	0.267	0.232	0.218	0.925	1.062	0.432	0.160	0.135	0.089
28	0.159	0.172*	0.330	0.253	0.227	0.219	0.904	1.041	0.402*	0.156	0.124	0.086
29	0.176	0.161*	0.348	0.249	0.000	0.216	0.971	0.883	0.387*	0.151	0.114	0.084
30	0.233	0.151*	0.342	0.238		0.229	1.140	0.856	0.376	0.149	0.107	0.083
31	0.219		4.175	0.233		0.247		0.842		0.146	0.104	

MONTHLY SUMMARY:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	4.682	7.326	22.751	9.953	6.485	6.822	29.500	78.286	15.259	7.350	5.238	3.136
TOTAL FLOW (cms days)	0.133	0.207	0.644	0.282	0.184	0.193	0.835	2.217	0.432	0.208	0.148	0.089
TOTAL DEPTH (in)	0.692	1.083	3.363	1.471	0.959	1.008	4.361	11.574	2.256	1.087	0.774	0.464
TOTAL DEPTH (cm)	1.758	2.751	8.543	3.737	2.435	2.562	11.077	29.397	5.730	2.760	1.967	1.178

ANNUAL SUMMARY:

Sum of Mean Daily Flow 196.788 cfs = 5.573 cms
Total Depth 29.092 in = 73.895 cm
Maximum Instantaneous Flow 13.500 cfs = 0.382 cms on December 31 at 23.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 210
WATERSHED AREA: 161 ACRES (65 HECTARES)

WATER YEAR 1977
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.082	0.159	0.086	0.064	0.082	0.101	0.101	0.850	0.250	0.116	0.069	0.088
2	0.121	0.114	0.084	0.063	0.082	0.099	0.101	0.749	0.240	0.135	0.068	0.074
3	0.134	0.102	0.084	0.059	0.082	0.098	0.101	0.653	0.232	0.123	0.066	0.071
4	0.102	0.095	0.077	0.059	0.082	0.098	0.154	0.529	0.224	0.134	0.065	0.067
5	0.097	0.090	0.072	0.057	0.082	0.097	0.193	0.467	0.206	0.127	0.064	0.067
6	0.098	0.090	0.068	0.055	0.082	0.097	0.253	0.429	0.190	0.120	0.063	0.064
7	0.083	0.088	0.078	0.051	0.082	0.095	0.377	0.443	0.203	0.105	0.061	0.061
8	0.079	0.088	0.091	0.050	0.081	0.096	0.579	0.427	0.266	0.101	0.060	0.058
9	0.078	0.088	0.095	0.050	0.080	0.096	0.568	0.387	0.203	0.100	0.059	0.058
10	0.108	0.085	0.094	0.050	0.080	0.096	0.477	0.395	0.191	0.095	0.057	0.057
11	0.126	0.083	0.094	0.046	0.081	0.096	0.438	0.369	0.204	0.093	0.056	0.056
12	0.092	0.081	0.094	0.043	0.089	0.097	0.471	0.340	0.213	0.092	0.056	0.054
13	0.086	0.076	0.092	0.045	0.109	0.098	0.495	0.322	0.219	0.090	0.055	0.053
14	0.080	0.075	0.089	0.046	0.095	0.097	0.455	0.312	0.197	0.085	0.055	0.053
15	0.078	0.083	0.086	0.048	0.090	0.119	0.481	0.308	0.183	0.084	0.054	0.102
16	0.077	0.108	0.086	0.053	0.093	0.097	0.472	0.321	0.169	0.081	0.052	0.135
17	0.076	0.106	0.086	0.074	0.093	0.096	0.436	0.366	0.157	0.083	0.051	0.123
18	0.074	0.135	0.083	0.114	0.100	0.096	0.436	0.377	0.150	0.140	0.048	0.074
19	0.070	0.099	0.079	0.087	0.101	0.093	0.419	0.410	0.147	0.104	0.049	0.080
20	0.069	0.091	0.074	0.072	0.112	0.092	0.432	0.391	0.154	0.091	0.048	0.161
21	0.068	0.088	0.071	0.078	0.115	0.092	0.480	0.398	0.146	0.089	0.050	0.150
22	0.068	0.091	0.070	0.087	0.107	0.103	0.605	0.390	0.138	0.085	0.063	0.111
23	0.066	0.086	0.068	0.088	0.097	0.112	0.857	0.394	0.132	0.078	0.052	0.096
24	0.065	0.099	0.069	0.089	0.097	0.108	1.161	0.383	0.126	0.139	0.086	0.101
25	0.115	0.116	0.071	0.090	0.101	0.104	1.350	0.350	0.123	0.116	0.115	0.113
26	0.101	0.082*	0.079	0.089	0.095	0.101	1.218	0.331	0.118	0.113	0.204	0.101
27	0.083	0.078*	0.078	0.087	0.094	0.101	1.016	0.320	0.115	0.084	0.160	0.088
28	0.082	0.075*	0.077	0.087	0.100	0.101	0.906	0.321	0.112	0.079	0.127	0.119
29	0.081	0.072*	0.077	0.086		0.101	0.828	0.290	0.110	0.075	0.137	0.143
30	0.082	0.084	0.075	0.085		0.101	0.795	0.272	0.108	0.073	0.253	0.156
31	0.082		0.071	0.083		0.101		0.253		0.071	0.142	

MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	2.704	2.807	2.492	2.132	2.582	3.077	16.655	12.546	5.224	3.098	2.546	2.734
TOTAL FLOW (cms days)	0.077	0.080	0.071	0.060	0.073	0.087	0.472	0.355	0.148	0.088	0.072	0.077
TOTAL DEPTH (in)	0.400	0.415	0.368	0.315	0.382	0.455	2.462	1.855	0.772	0.458	0.376	0.404
TOTAL DEPTH (cm)	1.015	1.054	0.936	0.801	0.970	1.155	6.254	4.711	1.962	1.163	0.956	1.027

ANNUAL SUMMARY:
Sum of Mean Daily Flow 58.598 cfs = 1.659 cms
Total Depth 8.663 in = 22.004 cm
Maximum Instantaneous Flow 1.520 cfs = 0.043 cms on April 25 at 13.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 210
WATERSHED AREA: 161 ACRES (65 HECTARES)

WATER YEAR 1978
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.125	0.108	0.265*	0.224*	0.139	0.214	2.854	1.652	0.766	0.269	0.148	0.114
2	0.105	0.174	1.239*	0.220*	0.140	0.216	2.499	1.629	0.716	0.270	0.144	0.107
3	0.094	0.124*	0.887*	0.215*	0.144	0.216	2.051	1.533	0.669	0.273	0.139	0.102
4	0.085	0.124*	0.704*	0.209*	0.146	0.216	1.719	1.401	0.623	0.507	0.136	0.099
5	0.081	0.139*	0.572*	0.205*	0.145	0.221	1.470	1.256	0.581	0.376	0.132	0.111
6	0.090	0.131*	0.511*	0.198*	0.177	0.237	1.336	1.156	0.544	0.340	0.126	0.129
7	0.152	0.127*	0.458*	0.193	0.164	0.223	1.218	1.083	0.504	0.533	0.124	0.160
8	0.121	0.121*	0.402*	0.189	0.162	0.241	1.110	1.054	0.470	0.414	0.121	0.132
9	0.167	0.121*	0.367*	0.183	0.161	0.290	1.056	1.108	0.467	0.389	0.119	0.114
10	0.132	0.122*	0.346*	0.172	0.160	0.271	1.085	1.334	0.531	0.378	0.122	0.112
11	0.123	0.123*	0.346*	0.160	0.161	0.272	1.231	1.447	0.451	0.355	0.122	0.180
12	0.116	0.123*	0.332*	0.155	0.159	0.284	1.195	1.364	0.409	0.329	0.130	0.195
13	0.106	0.129*	0.364*	0.153	0.158	0.285	1.167	1.356	0.389	0.301	0.217	0.139
14	0.098	0.142*	0.463*	0.154	0.158	0.287	1.104	1.365	0.378	0.282	0.160	0.130
15	0.091	0.174*	0.526*	0.153	0.158	0.280	1.104	1.377	0.376	0.280	0.213	0.120
16	0.087	0.145	0.528*	0.153	0.157	0.278	1.098	1.276	0.352	0.264	0.228	0.116
17	0.085	0.135	0.521*	0.154	0.153	0.297	1.035	1.169	0.330	0.255	0.206	0.119
18	0.082	0.127*	0.499*	0.151	0.152	0.347	1.018	1.089	0.339	0.241	0.165	0.130
19	0.077	0.121*	0.458*	0.151	0.150	0.419	1.058	1.032	0.318	0.232	0.148	0.119
20	0.076	0.116*	0.415*	0.151	0.155	0.512	1.087	0.993	0.295	0.221	0.140	0.111
21	0.075	0.112*	0.403	0.149	0.163	0.659	1.052	0.973	0.284	0.215	0.132	0.106
22	0.074	0.109*	0.382	0.148	0.160	0.859	0.998	1.003	0.283	0.207	0.284	0.105
23	0.073	0.110*	0.359	0.142	0.164	1.107	0.928	0.934	0.270	0.199	0.169	0.103
24	0.072	0.116*	0.335	0.138	0.175	1.197	0.896	0.965	0.344	0.189	0.148	0.099
25	0.189	0.332*	0.307	0.138	0.193	1.156	1.037	0.963	0.432	0.179	0.137	0.095
26	0.154	0.276*	0.281	0.140	0.201	1.153	1.305	0.947	0.310	0.171	0.131	0.092
27	0.104	0.210*	0.262	0.139	0.208	1.373	1.547	0.967	0.280	0.166	0.125	0.090
28	0.098	0.197*	0.256	0.138	0.210	1.801	1.578	0.975	0.260	0.209	0.118	0.102
29	0.096	0.260*	0.252	0.138		2.215	1.510	0.951	0.348	0.181	0.116	0.096
30	0.107	0.211*	0.245	0.138		2.602	1.550	0.880	0.290	0.164	0.117	0.099
31	0.103		0.233*	0.138		2.818		0.830		0.155	0.116	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	3.236	4.557	13.515	5.086	4.570	22.542	39.892	36.062	12.608	8.547	4.632	3.526
TOTAL FLOW (cms days)	0.092	0.129	0.383	0.144	0.129	0.638	1.130	1.021	0.357	0.242	0.131	0.100
TOTAL DEPTH (in)	0.478	0.674	1.998	0.752	0.676	3.332	5.898	5.331	1.864	1.263	0.685	0.521
TOTAL DEPTH (cm)	1.215	1.711	5.075	1.910	1.716	8.465	14.980	13.541	4.734	3.209	1.739	1.324

ANNUAL SUMMARY:
Sum of Mean Daily Flow 158.772 cfs = 4.496 cms
Total Depth 23.472 in = 59.619 cm
Maximum Instantaneous Flow 2.970 cfs = 0.084 cms on April 1 at 13.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 210
WATERSHED AREA: 161 ACRES (65 HECTARES)

WATER YEAR 1979
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.095	0.068	0.075	0.066	0.057	0.094*	0.212	2.091	0.404	0.184	0.067	0.084
2	0.091	0.070	0.075	0.066	0.057	0.094*	0.198	2.120	0.389	0.173	0.066	0.073
3	0.089	0.069	0.095	0.066	0.057	0.094*	0.185	2.086	0.365	0.163	0.065	0.069
4	0.076	0.076	0.110	0.066	0.058	0.092*	0.175	2.165	0.349	0.157	0.065	0.069
5	0.071	0.064	0.092	0.055	0.060	0.115*	0.207	2.312	0.343	0.150	0.063	0.063
6	0.071	0.064	0.092	0.052	0.063	0.191*	0.224	2.333	0.391	0.147	0.062	0.059
7	0.072	0.065	0.089	0.051	0.065	0.211*	0.288	2.015	0.346*	0.150	0.061	0.057
8	0.070	0.256	0.081	0.051	0.067	0.163*	0.302	1.697	0.316*	0.139	0.060	0.055
9	0.070	0.098	0.076	0.050	0.070*	0.145*	0.337	1.512	0.297*	0.135	0.057	0.058
10	0.069	0.075	0.068	0.048	0.077*	0.135	0.327	1.403	0.280*	0.134	0.056	0.071
11	0.067	0.075	0.061	0.046	0.088*	0.129	0.311	1.350	0.266*	0.132	0.055	0.060
12	0.066	0.075	0.061	0.048	0.130*	0.129	0.296	1.321	0.255*	0.118	0.058	0.054
13	0.062	0.075	0.060	0.047	0.196*	0.132	0.278	1.371	0.244*	0.103	0.064	0.054
14	0.059	0.075	0.060	0.050	0.126*	0.139	0.259	1.445	0.225*	0.099	0.064	0.052
15	0.059	0.075	0.060	0.053	0.105*	0.161	0.260	1.556	0.219*	0.097	0.090	0.051
16	0.060	0.075	0.061	0.053	0.100*	0.179	0.303	1.578	0.215	0.093	0.071	0.050
17	0.061	0.075	0.061	0.053	0.097*	0.176	0.436	1.454	0.231	0.089	0.067	0.049
18	0.064	0.075	0.061	0.054	0.097*	0.164	0.473	1.333	0.267	0.087	0.064	0.047
19	0.064	0.076	0.061	0.054	0.095*	0.159	0.496	1.206	0.242	0.084	0.069	0.047
20	0.064	0.075	0.061	0.055	0.096*	0.158	0.463	1.093	0.224	0.084	0.063	0.046
21	0.064	0.075	0.062	0.055	0.097*	0.158	0.443	0.975	0.315	0.081	0.073	0.046
22	0.064	0.075	0.064	0.055	0.097*	0.162	0.491	0.884	0.240	0.098	0.067	0.046
23	0.063	0.075	0.068	0.055	0.097*	0.172	0.550	0.838	0.218	0.084	0.147	0.045
24	0.063	0.075	0.067	0.057	0.096*	0.202	0.657	0.772	0.204	0.079	0.088	0.044
25	0.063	0.075	0.067	0.057	0.096*	0.215	0.744	0.685	0.192	0.076	0.070	0.044
26	0.062	0.075	0.066	0.057	0.095*	0.214	0.895	0.627	0.179	0.072	0.071	0.046
27	0.062	0.075	0.066	0.057	0.095*	0.228	1.156	0.580	0.172	0.072	0.071	0.044
28	0.061	0.075	0.065	0.057	0.095*	0.265	1.518	0.545	0.164	0.082	0.065	0.042
29	0.066	0.075	0.064	0.057		0.258	1.908	0.499	0.162	0.078	0.092	0.043
30	0.067	0.075	0.064	0.057		0.243	2.074	0.463	0.175	0.072	0.145	0.043
31	0.063		0.066	0.057		0.227		0.435		0.068	0.150	
MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	2.098	2.404	2.179	1.704	2.527	5.201	16.466	40.738	7.887	3.376	2.328	1.609
TOTAL FLOW (cms days)	0.059	0.068	0.062	0.048	0.072	0.147	0.466	1.154	0.223	0.096	0.066	0.046
TOTAL DEPTH (in)	0.310	0.355	0.322	0.252	0.374	0.769	2.434	6.023	1.166	0.499	0.344	0.238
TOTAL DEPTH (cm)	0.788	0.903	0.818	0.640	0.949	1.953	6.183	15.297	2.962	1.268	0.874	0.604

ANNUAL SUMMARY:
Sum of Mean Daily Flow 88.517 cfs = 2.507 cms
Total Depth 13.086 in = 33.239 cm
Maximum Instantaneous Flow 2.350 cfs = 0.067 cms on May 6 at 18.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 212
WATERSHED AREA: 207 ACRES (83 HECTARES)

WATER YEAR 1975
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.100*	0.124	0.105	0.115	0.131	0.159	0.108	0.177	4.333	0.830	0.289	0.221
2	0.101*	0.116	0.105	0.119	0.130	0.187	0.108	0.205	4.851	0.787	0.276	0.211
3	0.101*	0.113	0.111	0.122	0.129	0.161	0.108	0.258	5.110	0.742	0.268	0.200
4	0.102*	0.113	0.122	0.122	0.129	0.155	0.108	0.235	4.657	0.702	0.261	0.191
5	0.103*	0.113	0.120	0.121	0.133	0.150	0.108	0.229	4.417	0.670	0.255	0.185
6	0.103*	0.118	0.116	0.120	0.132	0.146	0.107	0.220	4.547	0.643	0.248	0.180
7	0.103*	0.124	0.115*	0.118	0.132	0.145	0.107	0.255	4.466	0.617	0.295	0.176
8	0.102*	0.119	0.115*	0.117	0.131	0.146	0.106	0.293	3.940	0.589	0.250	0.172
9	0.101	0.114	0.115*	0.117	0.131	0.149	0.106	0.413	3.496	0.563	0.242	0.169
10	0.103	0.114	0.117	0.117	0.131	0.145	0.109	0.597	3.207	0.537	0.234	0.166
11	0.119	0.111	0.125	0.114	0.130	0.134	0.115	0.892	3.102	0.514	0.229	0.163
12	0.109	0.135	0.118*	0.114	0.130	0.121	0.125	1.088	3.066	0.499	0.224	0.161
13	0.106	0.131	0.119*	0.121	0.132	0.119	0.138	1.182	2.938	0.503	0.218	0.158
14	0.105	0.123	0.118*	0.130	0.131	0.118	0.150	1.643	2.709	0.494	0.215	0.154
15	0.104	0.121	0.120	0.129	0.130	0.117	0.194	2.647	2.456	0.488	0.232	0.154
16	0.102	0.118	0.141	0.122	0.129	0.116	0.188	3.134	2.158	0.461	0.218*	0.210
17	0.102	0.117	0.129	0.431	0.129	0.114	0.166	2.949	1.895	0.437	0.263*	0.205
18	0.101	0.120	0.132	0.444	0.129	0.117	0.155	2.810	1.709	0.418	0.287*	0.169
19	0.103	0.114	0.122	0.210	0.127	0.119	0.152	2.554	1.567	0.402	0.262*	0.160
20	0.102	0.126	0.135*	0.178	0.126	0.115	0.157	2.115	1.594	0.389	0.252*	0.155
21	0.130	0.137	0.147*	0.159	0.125	0.114	0.158	1.768	1.430	0.378	0.214	0.152
22	0.124	0.141	0.123*	0.152	0.124	0.114	0.178	1.540	1.306	0.365	0.221	0.148
23	0.118	0.120	0.123	0.165	0.126	0.113	0.201	1.610	1.210	0.342	0.437	0.146
24	0.114	0.121	0.120	0.156	0.128	0.113	0.197	1.735	1.154	0.330	0.371	0.144
25	0.110	0.122	0.122	0.147	0.126	0.113	0.206	1.688	1.093	0.319	0.268	0.142
26	0.107	0.116	0.119	0.143	0.126	0.112	0.191	1.535	1.001	0.310	0.241	0.141
27	0.109	0.115	0.119	0.140	0.126	0.111	0.184	1.463	0.967	0.303	0.233	0.139
28	0.112	0.113	0.118	0.137	0.150	0.109	0.174	1.531	0.907	0.303	0.271	0.136
29	0.111	0.110	0.116	0.134		0.108	0.171	1.912	0.856	0.380	0.230	0.137
30	0.108	0.106	0.115	0.132		0.109	0.174	2.691	0.825	0.311	0.216	0.136
31	0.111		0.114	0.131		0.109		3.570		0.303	0.222	

MONTHLY SUMMARY:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	3.325	3.584	3.736	4.776	3.630	3.955	4.449	44.934	76.963	14.930	7.940	4.981
TOTAL FLOW (cms days)	0.094	0.102	0.106	0.135	0.103	0.112	0.126	1.273	2.180	0.423	0.225	0.141
TOTAL DEPTH (in)	0.382	0.412	0.430	0.549	0.417	0.455	0.512	5.167	8.850	1.717	0.913	0.573
TOTAL DEPTH (cm)	0.971	1.047	1.091	1.395	1.060	1.155	1.299	13.123	22.478	4.360	2.319	1.455

ANNUAL SUMMARY:

Sum of Mean Daily Flow 177.203 cfs = 5.018 cms
Total Depth 20.375 in = 51.754 cm
Maximum Instantaneous Flow 5.220 cfs = 0.148 cms on June 2 at 12.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 212
WATERSHED AREA: 207 ACRES (83 HECTARES)

WATER YEAR 1976
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.135	0.263	0.683*	1.178*	0.398*	0.329	0.331	1.486	1.588	0.649	0.305	0.216
2	0.133	0.306	0.736*	0.383*	0.398*	0.326	0.327	1.939	1.472	0.621	0.292	0.211
3	0.129	0.359	0.696*	0.383*	0.391*	0.320	0.339	2.565	1.386	0.594	0.343	0.208
4	0.197	0.398	0.732*	0.383*	0.380*	0.317	0.376	3.601	1.303	0.568	0.292	0.206
5	0.146	0.457	0.711*	0.368*	0.374*	0.317	0.467	3.978	1.225	0.544	0.274	0.203
6	0.167	0.461*	0.667*	0.367*	0.369*	0.316	0.526	3.782	1.174	0.521	0.263	0.300
7	0.220	0.436*	0.765*	0.359*	0.364*	0.315	0.648	3.873	1.143	0.504	0.551	0.221
8	0.180	0.394*	0.919*	0.354*	0.359*	0.315	0.891	4.456	1.107	0.489	0.466	0.209
9	0.160	0.360*	0.998*	0.349*	0.349*	0.314	1.144	5.309	1.048	0.471	0.366	0.204
10	0.153	0.342*	0.994*	0.343*	0.349*	0.314	1.332	6.117	1.050	0.454	0.328	0.200
11	0.203	0.319*	0.912*	0.340*	0.346*	0.315	1.538	6.684	0.969	0.441	0.304	0.225
12	0.219	0.299*	0.848*	0.338*	0.341*	0.312	1.810	5.686	0.959	0.573	0.292	0.209
13	0.193	0.290*	0.775*	0.323*	0.337*	0.309	1.912	5.421	0.942	0.451	0.286	0.198
14	0.178	0.289*	0.706*	0.325*	0.337*	0.300	1.910	5.687	0.908	0.425	0.277	0.191
15	0.188	0.313*	0.654*	0.506*	0.339*	0.296	1.813	4.939	0.858	0.405	0.354	0.187
16	0.170	0.292*	0.606*	0.545*	0.336*	0.296	1.637	4.463	1.045	0.389	0.318	0.204
17	0.164	0.276*	0.568*	0.534*	0.335*	0.308	1.490	4.145	1.087	0.384	0.287	0.196
18	0.182	0.274*	0.541*	0.545*	0.329*	0.312	1.361	3.727	1.061	0.406	0.277	0.197
19	0.185	0.318*	0.516*	0.532*	0.329*	0.308	1.243	3.453	1.048	0.377	0.270	0.187
20	0.211	0.228*	0.508*	0.524*	0.326*	0.300	1.198	3.168	1.060	0.359	0.265	0.181
21	0.504	0.222*	0.504*	0.510*	0.325*	0.296	1.123	2.988	1.068	0.371	0.258	0.176
22	0.355	0.221*	0.501*	0.502*	0.327*	0.305	1.070	2.912	1.021	0.344	0.258	0.179
23	0.300	0.212*	0.446*	0.487*	0.325*	0.309	1.037	2.902	0.971	0.331	0.277	0.210
24	0.266	0.261*	0.446*	0.477*	0.328*	0.309	1.065	2.921	0.943	0.380	0.253	0.183
25	0.255	0.227*	0.429*	0.464*	0.329	0.307	1.070	2.702	0.926	0.337	0.335	0.178
26	0.249	0.221*	0.406*	0.444*	0.329	0.305	1.063	2.374	0.888	0.319	0.286	0.173
27	0.228	0.214*	0.433*	0.435*	0.337	0.305	1.050	2.334	0.843	0.305	0.261	0.169
28	0.221	0.208*	0.456*	0.423*	0.336	0.309	1.026	2.146	0.793	0.296	0.248	0.165
29	0.242	0.198*	0.418*	0.420*	0.329	0.305	1.065	1.906	0.728	0.291	0.237	0.161
30	0.289	0.191*	0.415*	0.405*		0.319	1.183	1.821	0.671	0.289	0.230	0.159
31	0.267		0.840*	0.402*		0.333		1.728		0.284	0.223	

MONTHLY SUMMARY:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	6.689	8.845	19.829	13.946	10.053	9.640	33.045	111.209	31.285	13.169	9.274	5.904
TOTAL FLOW (cms days)	0.189	0.250	0.562	0.395	0.285	0.273	0.936	3.149	0.886	0.373	0.263	0.167
TOTAL DEPTH (in)	0.769	1.017	2.280	1.604	1.156	1.108	3.800	12.787	3.597	1.514	1.066	0.679
TOTAL DEPTH (cm)	1.954	2.583	5.791	4.073	2.936	2.815	9.651	32.480	9.137	3.846	2.709	1.724

ANNUAL SUMMARY:
Sum of Mean Daily Flow 272.888 cfs = 7.728 cms
Total Depth 31.378 in = 79.699 cm
Maximum Instantaneous Flow 7.250 cfs = 0.205 cms on May 10 at 22.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 212
WATERSHED AREA: 207 ACRES (83 HECTARES)

WATER YEAR 1977
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.158	0.241	0.137	0.120	0.109	0.127	0.124	1.192	0.365	0.186	0.120	0.134
2	0.211	0.188	0.139	0.120	0.109	0.124	0.124	1.151	0.349	0.205	0.118	0.124
3	0.215	0.178	0.140	0.120	0.109	0.123	0.123	1.029	0.336	0.191	0.117	0.117
4	0.179	0.172	0.136	0.120	0.109	0.122	0.153	0.875	0.322	0.201	0.114	0.113
5	0.175	0.167	0.131	0.120	0.108	0.122	0.181	0.766	0.309	0.190	0.112	0.111
6	0.176	0.164	0.127	0.120	0.106	0.125	0.221	0.693	0.299	0.182	0.110	0.108
7	0.171	0.161	0.139	0.120	0.105	0.130	0.303	0.680	0.299	0.169	0.109	0.107
8	0.166	0.159	0.146	0.120	0.105	0.127	0.431	0.652	0.354	0.163	0.108	0.105
9	0.162	0.158	0.143	0.120	0.104	0.124	0.432	0.626	0.295	0.161	0.106	0.104
10	0.192	0.156	0.141	0.120	0.104	0.124	0.369	0.641	0.283	0.158	0.105	0.102
11	0.206	0.155	0.140	0.116	0.108	0.124	0.346	0.599	0.289	0.154	0.103	0.101
12	0.174	0.150	0.139	0.099	0.114	0.124	0.368	0.555	0.282	0.153	0.102	0.100
13	0.169	0.147	0.137	0.102	0.129	0.124	0.389	0.519	0.286	0.150	0.101	0.098
14	0.162	0.145	0.135	0.103	0.115	0.122	0.364	0.493	0.273	0.147	0.101	0.097
15	0.158	0.153	0.133	0.105	0.112	0.119	0.375	0.482	0.260	0.143	0.099	0.143
16	0.157	0.177	0.133	0.109	0.116	0.118	0.381	0.473	0.247	0.140	0.098	0.175
17	0.156	0.182	0.134	0.132	0.119	0.118	0.361	0.489	0.238	0.140	0.097	0.160
18	0.155	0.197	0.131	0.168	0.124	0.120	0.360	0.487	0.230	0.190	0.095	0.120
19	0.155	0.167	0.126	0.140	0.125	0.121*	0.357	0.517	0.248	0.162	0.095	0.121
20	0.155	0.155	0.123	0.125	0.133	0.121*	0.363	0.502	0.232	0.148	0.094	0.195
21	0.154	0.157	0.122	0.122	0.139	0.121	0.400	0.506	0.224	0.144	0.095	0.182
22	0.152	0.157	0.122	0.121	0.131	0.123*	0.500	0.503	0.216	0.141	0.104	0.148
23	0.151	0.154	0.123	0.119	0.128	0.127*	0.701	0.509	0.209	0.132	0.096	0.133
24	0.150	0.169	0.123	0.117	0.129	0.129*	0.997	0.504	0.204	0.183	0.126	0.136
25	0.200	0.180	0.125	0.115	0.121	0.129	1.313	0.470	0.201	0.164	0.155	0.150
26	0.184	0.149*	0.134	0.113	0.123	0.130	1.376	0.451	0.196	0.166	0.233	0.137
27	0.165	0.136*	0.131	0.113	0.122	0.130	1.205	0.441	0.188	0.138	0.189	0.127
28	0.161	0.127	0.128	0.113	0.128	0.130	1.097	0.438	0.185	0.128	0.147	0.155
29	0.156	0.140	0.127	0.111		0.128	1.055	0.407	0.182	0.126	0.156	0.172
30	0.156	0.141	0.126	0.110		0.126	1.078	0.385	0.179	0.124	0.290	0.190
31	0.156		0.122	0.110		0.124		0.364		0.123	0.167	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	5.237	4.880	4.090	3.663	3.282	3.854	15.846	18.398	7.775	4.899	3.862	3.965
TOTAL FLOW (cms days)	0.148	0.138	0.116	0.104	0.093	0.109	0.449	0.521	0.220	0.139	0.109	0.112
TOTAL DEPTH (in)	0.602	0.561	0.470	0.421	0.377	0.443	1.822	2.115	0.894	0.563	0.444	0.456
TOTAL DEPTH (cm)	1.529	1.425	1.195	1.070	0.959	1.125	4.628	5.373	2.271	1.431	1.128	1.158

ANNUAL SUMMARY:
Sum of Mean Daily Flow 79.750 cfs = 2.259 cms
Total Depth 9.170 in = 23.292 cm
Maximum Instantaneous Flow 1.960 cfs = 0.056 cms on May 1 at 1.30 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 212
WATERSHED AREA: 207 ACRES (83 HECTARES)

WATER YEAR 1978
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.153	0.146	0.287	0.253	0.208	0.245	3.405	2.157	1.281	0.448	0.278	0.198
2	0.141	0.193	1.103	0.248	0.208	0.247	3.141	2.221	1.237	0.445	0.273	0.192
3	0.131	0.141	0.944	0.248	0.211	0.248	2.577	2.163	1.183	0.506	0.266	0.188
4	0.127	0.142	0.770	0.250	0.213	0.250	2.151	1.998	1.124	0.667	0.263	0.183
5	0.122	0.156	0.635	0.251	0.215	0.259	1.819	1.807	1.062	0.568	0.254	0.194
6	0.132	0.146	0.560	0.249	0.238	0.265	1.640	1.668	1.000	0.539	0.247	0.203
7	0.181	0.143	0.507	0.242	0.226	0.260	1.495	1.570	0.940	0.713	0.243	0.238
8	0.154	0.136*	0.442	0.247	0.218	0.272	1.367	1.527	0.888	0.615	0.239	0.208
9	0.200	0.135*	0.404	0.248	0.216	0.311	1.289	1.580	0.863	0.594	0.232	0.190
10	0.161	0.136	0.380	0.241	0.215	0.290	1.276	1.880	0.897	0.585	0.227	0.189
11	0.158	0.137	0.381	0.236	0.213	0.291	1.370	2.141	0.805	0.559	0.228	0.228
12	0.153	0.139	0.364	0.233	0.212	0.299	1.344	2.040	0.754	0.531	0.242	0.275
13	0.143	0.146	0.399	0.229	0.212	0.304	1.347	2.006	0.712	0.495	0.301	0.226
14	0.135	0.159	0.510	0.229	0.211	0.309	1.332	2.089	0.672	0.482	0.251	0.216
15	0.130	0.197	0.574	0.230	0.211	0.307	1.325	2.214	0.652	0.484	0.299	0.200
16	0.126	0.164	0.591	0.229	0.210	0.307	1.319	2.068	0.626	0.455	0.313	0.192
17	0.124	0.151*	0.611	0.229	0.208	0.322	1.252	1.889	0.603	0.440	0.306	0.192
18	0.121	0.142*	0.591	0.225	0.207	0.361	1.229	1.753	0.611	0.420	0.262	0.197
19	0.118	0.135*	0.539	0.223	0.208	0.403	1.250	1.705	0.579	0.399	0.241	0.193
20	0.116	0.128*	0.487	0.220	0.214	0.462	1.282	1.723	0.556	0.383	0.234	0.185
21	0.114	0.122*	0.464	0.220	0.214	0.569	1.260	1.759	0.538	0.370	0.226	0.179
22	0.112	0.120	0.451	0.218	0.214	0.726	1.228	1.798	0.528	0.357	0.357	0.177
23	0.111	0.122	0.420	0.215	0.216	0.931	1.174	1.647	0.507	0.349	0.259	0.172
24	0.110	0.130	0.389	0.211	0.231	1.088	1.131	1.567	0.569	0.336	0.238	0.168
25	0.231	0.365	0.362	0.212	0.240	1.137	1.228	1.494	0.645	0.324	0.226	0.166
26	0.175	0.305	0.340	0.210	0.240	1.176	1.435	1.434	0.523	0.317	0.220	0.163
27	0.141	0.233	0.326	0.207	0.242	1.311	1.723	1.425	0.487	0.311	0.212	0.160
28	0.136	0.216	0.326	0.207	0.243	1.686	1.928	1.495	0.469	0.366	0.206	0.169
29	0.133	0.285	0.326	0.206		2.188	1.954	1.497	0.543	0.313	0.203	0.166
30	0.141	0.235	0.308	0.206		2.745	1.939	1.406	0.472	0.295	0.203	0.165
31	0.137		0.284	0.207		3.189		1.343		0.283	0.203	
MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	4.366	5.105	15.072	7.079	6.112	22.758	48.208	55.062	22.323	13.950	7.752	5.770
TOTAL FLOW (cms days)	0.124	0.145	0.427	0.200	0.173	0.645	1.365	1.559	0.632	0.395	0.220	0.163
TOTAL DEPTH (in)	0.502	0.587	1.733	0.814	0.703	2.617	5.543	6.331	2.567	1.604	0.891	0.663
TOTAL DEPTH (cm)	1.275	1.491	4.402	2.067	1.785	6.647	14.079	16.081	6.520	4.074	2.264	1.685

ANNUAL SUMMARY:
Sum of Mean Daily Flow 213.557 cfs = 6.048 cms
Total Depth 24.556 in = 62.371 cm
Maximum Instantaneous Flow 3.490 cfs = 0.099 cms on April 1 at 23.30 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 212
WATERSHED AREA: 207 ACRES (83 HECTARES)

WATER YEAR 1979
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.166	0.140	0.132	0.112	0.104	0.128	0.204	2.096	0.747	0.283	0.136	0.137
2	0.160	0.137	0.135	0.111	0.104	0.129	0.195	2.219	0.702	0.269	0.134	0.126
3	0.155	0.130	0.136	0.111	0.104	0.128	0.190	2.288	0.664	0.261	0.132	0.122
4	0.154	0.138	0.177	0.110	0.104	0.128	0.189	2.466	0.632	0.252	0.130	0.121
5	0.152	0.128	0.142	0.111	0.106	0.155	0.225	3.065	0.611	0.241	0.130	0.114
6	0.151	0.125	0.136	0.111	0.108	0.245	0.249	2.955	0.630	0.234	0.127	0.110
7	0.150	0.126	0.130	0.110	0.110	0.267	0.287	2.430	0.577	0.229	0.125	0.109
8	0.147	0.312	0.127	0.110	0.106	0.195	0.286	2.036	0.540	0.220	0.124	0.106
9	0.145	0.173	0.124	0.111	0.103	0.159	0.308	1.743	0.510	0.213	0.121	0.108
10	0.144	0.128	0.120	0.110	0.113	0.151	0.308	1.544	0.486	0.211	0.119	0.119
11	0.143	0.122	0.126	0.106	0.127	0.147	0.303	1.470	0.466	0.209	0.116	0.107
12	0.143	0.120	0.126	0.104	0.178	0.151	0.296	1.455	0.449	0.203	0.119	0.101
13	0.142	0.122	0.125	0.104	0.259	0.151	0.285	1.539	0.433	0.194	0.125	0.098
14	0.143	0.115	0.124	0.104	0.173	0.154	0.276	1.702	0.410	0.189	0.126	0.096
15	0.142	0.112	0.125	0.104	0.148	0.168	0.277	2.015	0.392	0.184	0.145	0.094
16	0.140	0.116	0.127	0.104	0.141	0.186	0.307	2.248	0.380	0.178	0.129	0.091
17	0.139	0.120	0.127	0.104	0.137	0.182	0.405	2.152	0.391	0.174	0.124	0.091
18	0.139	0.125	0.128	0.104	0.136	0.174	0.414	1.972	0.412	0.169	0.118	0.089
19	0.136	0.130	0.127	0.104	0.133	0.168	0.430	1.841	0.381	0.167	0.118	0.088
20	0.136	0.133	0.126	0.104	0.132	0.166	0.421	1.749	0.360	0.163	0.114	0.089
21	0.136	0.133	0.124	0.104	0.133	0.167	0.409	1.659	0.413	0.161	0.123	0.089
22	0.135	0.133	0.126	0.105	0.133	0.169	0.459	1.604	0.351	0.172	0.119	0.089
23	0.139	0.130	0.129	0.104	0.132	0.175	0.497	1.563	0.329	0.161	0.176	0.087
24	0.137	0.131	0.130	0.104	0.131	0.193	0.567	1.480	0.314	0.156	0.150	0.086
25	0.137	0.131	0.131	0.104	0.131	0.203	0.635	1.329	0.301	0.152	0.124	0.086
26	0.135	0.131	0.131	0.104	0.131	0.199	0.748	1.209	0.290	0.149	0.122	0.090
27	0.133	0.131	0.130	0.104	0.130	0.211	0.946	1.106	0.284	0.146	0.122	0.090
28	0.134	0.131	0.128	0.103	0.129	0.242	1.251	1.023	0.275	0.150	0.119	0.088
29	0.131	0.129	0.124	0.104		0.228	1.616	0.931	0.271	0.146	0.148	0.088
30	0.131	0.133	0.116	0.104		0.219	1.923	0.856	0.281	0.140	0.211	0.086
31	0.131		0.113	0.104		0.212		0.800		0.135	0.201	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	4.401	4.065	4.001	3.291	3.674	5.550	14.906	54.543	13.283	5.911	4.123	2.994
TOTAL FLOW (cms days)	0.125	0.115	0.113	0.093	0.104	0.157	0.422	1.545	0.376	0.167	0.117	0.085
TOTAL DEPTH (in)	0.506	0.467	0.460	0.378	0.422	0.638	1.714	6.272	1.527	0.680	0.474	0.344
TOTAL DEPTH (cm)	1.285	1.187	1.168	0.961	1.073	1.621	4.353	15.930	3.879	1.726	1.204	0.874

ANNUAL SUMMARY:

Sum of Mean Daily Flow 120.742 cfs = 3.419 cms
Total Depth 13.883 in = 35.264 cm
Maximum Instantaneous Flow 3.180 cfs = 0.090 cms on May 5 at 16.00 hours

*** Indicates some data were estimated during this day.**

HORSE CREEK STUDY AREA
WATERSHED: 214
WATERSHED AREA: 154 ACRES (62 HECTARES)

WATER YEAR 1975
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.040	0.042	0.045*	0.039	0.060*	0.078*	0.073	0.149	3.923	0.745	0.173	0.139
2	0.039	0.039	0.043	0.038	0.060*	0.096*	0.074	0.184	4.535	0.686	0.161	0.132
3	0.039	0.038	0.041	0.039	0.060*	0.080*	0.075	0.263	4.745	0.637	0.153	0.122
4	0.036	0.035	0.044	0.040	0.060*	0.076*	0.075	0.243	4.138	0.595	0.146	0.115
5	0.034	0.035	0.042	0.040	0.060*	0.075*	0.075	0.225	4.087	0.558	0.140	0.110
6	0.034	0.039	0.041	0.039	0.060*	0.074*	0.074	0.207	4.408	0.525	0.135	0.104
7	0.034	0.045	0.041	0.041	0.060*	0.074*	0.074	0.231	4.164	0.494	0.165	0.097
8	0.032	0.046	0.041*	0.040	0.060*	0.075*	0.074	0.260	3.815	0.457	0.141	0.092
9	0.030	0.038	0.041*	0.041	0.059*	0.081*	0.070	0.443	3.211	0.421	0.131	0.088
10	0.030	0.039	0.041	0.041*	0.058*	0.082*	0.065	0.624	2.784	0.393	0.126	0.086
11	0.041	0.037	0.040	0.041*	0.058*	0.067*	0.072	0.939	2.599	0.372	0.122	0.084
12	0.034	0.051	0.040	0.042*	0.057*	0.060	0.090	1.142	2.456	0.363	0.117	0.081
13	0.032	0.054	0.040	0.042	0.056*	0.060	0.105	1.242	2.330	0.387	0.114	0.079
14	0.031	0.042	0.040	0.044	0.056*	0.058	0.127	1.729	2.145	0.354	0.110	0.076
15	0.030	0.040	0.040	0.047	0.056*	0.057	0.155	2.585	2.057	0.349	0.107	0.077
16	0.030	0.037	0.051	0.043	0.056*	0.056	0.144	2.572	1.980	0.329	0.100	0.119
17	0.029	0.039	0.046	0.260	0.056*	0.056	0.120	2.364	1.772	0.311	0.104*	0.117
18	0.029	0.044	0.044	0.329	0.055*	0.057	0.109	2.194	1.628	0.293	0.151*	0.095
19	0.028	0.042	0.043	0.131	0.054*	0.058	0.109	1.872	1.503	0.276	0.181*	0.086
20	0.029	0.047	0.046	0.096	0.054*	0.056	0.108	1.447	1.451	0.263	0.164*	0.080
21	0.044	0.058	0.055	0.080	0.054*	0.056	0.118	1.246	1.308	0.241	0.144*	0.077
22	0.043	0.060	0.059	0.072	0.053*	0.055	0.145	1.157	1.198	0.222	0.137	0.074
23	0.040	0.046	0.050*	0.077	0.054*	0.054	0.159	1.356	1.130	0.217	0.169	0.072
24	0.038	0.048	0.047*	0.073	0.058*	0.053	0.174	1.481	1.076	0.202	0.376	0.069
25	0.036	0.049	0.044	0.065	0.057*	0.053	0.186	1.277	1.017	0.192	0.216	0.067
26	0.034	0.044	0.042	0.061	0.056*	0.053	0.172	1.302	0.971	0.184	0.171	0.067
27	0.034	0.043	0.041	0.060	0.056*	0.053	0.162	1.155	0.962	0.176	0.152	0.066
28	0.036	0.041*	0.041	0.059	0.071*	0.065	0.151	1.277	0.941	0.176	0.174	0.063
29	0.035	0.043*	0.041*	0.059		0.072	0.140	1.779	0.855	0.247	0.150	0.062
30	0.036*	0.044*	0.040*	0.059*		0.073	0.140	2.496	0.784	0.196	0.137	0.064
31	0.039*		0.039	0.060*		0.073		3.202		0.187	0.141	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	1.075	1.302	1.344	2.194	1.608	2.034	3.417	38.641	69.970	11.044	4.706	2.657
TOTAL FLOW (cms days)	0.030	0.037	0.038	0.062	0.046	0.058	0.097	1.094	1.982	0.313	0.133	0.075
TOTAL DEPTH (in)	0.166	0.201	0.208	0.339	0.249	0.314	0.528	5.972	10.814	1.707	0.727	0.411
TOTAL DEPTH (cm)	0.422	0.511	0.528	0.862	0.631	0.799	1.341	15.169	27.468	4.336	1.847	1.043

ANNUAL SUMMARY:
Sum of Mean Daily Flow 139.992 cfs = 3.965 cms
Total Depth 21.637 in = 54.957 cm
Maximum Instantaneous Flow 4.890 cfs = 0.138 cms on June 3 at 6.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 214
WATERSHED AREA: 154 ACRES (62 HECTARES)

WATER YEAR 1976
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.061	0.191	0.545	1.058	0.324	0.231	0.238	1.329	1.155	0.531	0.195	0.101
2	0.060	0.222	0.653	0.317	0.320	0.228	0.232	1.720	1.039	0.501	0.183	0.097
3	0.055	0.281	0.608	0.315	0.318	0.225	0.244	2.070	0.978	0.468	0.220	0.094
4	0.096	0.326	0.633	0.316	0.312*	0.223	0.287	2.869	0.906	0.444	0.189	0.091
5	0.065	0.369	0.619	0.313	0.309*	0.222	0.380	2.921	0.823	0.421	0.171	0.088
6	0.073	0.381	0.580	0.301	0.304*	0.222	0.429	2.825	0.805	0.398	0.158	0.158
7	0.122	0.360	0.653	0.293	0.301*	0.222	0.560	3.147	0.809	0.381	0.421	0.111
8	0.095	0.322	0.783	0.289	0.297*	0.221	0.825	3.836	0.816*	0.365	0.333	0.099
9	0.082	0.291	0.870	0.280	0.294*	0.219	1.017	4.537	0.764*	0.347	0.260	0.090
10	0.074	0.273	0.874	0.277	0.290*	0.218	1.104	5.287	0.771*	0.330	0.224	0.085
11	0.109	0.254	0.806	0.273	0.286*	0.218	1.256	5.607	0.704*	0.315	0.203	0.098
12	0.129	0.236	0.746	0.267	0.280*	0.217	1.422	4.725	0.730*	0.422	0.194	0.098
13	0.120	0.226	0.681	0.260	0.273	0.217	1.405	4.550	0.726*	0.326	0.187	0.087
14	0.112	0.226	0.618	0.262	0.267	0.216	1.347	4.886	0.673*	0.298	0.181	0.082
15	0.113	0.244	0.570	0.421	0.265	0.214	1.250	4.322	0.632*	0.280	0.253	0.078
16	0.101	0.230	0.527	0.457	0.260	0.213	1.119	3.927	0.828*	0.264	0.220	0.091
17	0.093	0.211	0.493	0.450	0.256	0.219	1.014	3.668	0.873*	0.260	0.177	0.089
18	0.103	0.209	0.465	0.457	0.251	0.223	0.935	3.246	0.769*	0.284	0.150	0.088
19	0.101	0.251	0.441	0.453	0.250	0.216	0.859	3.013	0.737	0.259	0.145	0.081
20	0.133	0.173	0.432	0.441	0.243	0.207	0.825	2.778	0.796*	0.242	0.140	0.076
21	0.350	0.174	0.424	0.433	0.249	0.203	0.788	2.560	0.825*	0.251	0.135	0.073
22	0.271	0.173	0.419	0.423	0.236	0.206	0.753	2.372	0.785*	0.226	0.133	0.075
23	0.210	0.166	0.373	0.413	0.234	0.210	0.740	2.465	0.741	0.212	0.149	0.096
24	0.182	0.205	0.372	0.402	0.232	0.209	0.795	2.505	0.708*	0.252	0.131	0.082
25	0.170	0.182	0.361	0.388	0.228	0.209	0.798	2.272	0.701*	0.218	0.184	0.076
26	0.165	0.176	0.381	0.373	0.229	0.209	0.782	2.070	0.669*	0.200	0.166	0.073
27	0.152	0.171	0.356	0.363	0.230	0.209	0.760	1.928	0.628*	0.187	0.142	0.071
28	0.143	0.165	0.339	0.353	0.235	0.207	0.749	1.739	0.616*	0.181	0.130	0.068
29	0.153	0.155	0.350	0.347	0.233	0.203	0.824	1.523	0.608	0.176	0.120	0.066
30	0.196	0.150	0.347	0.336		0.214	0.984	1.415	0.567	0.173	0.112	0.063
31	0.205		0.801	0.328		0.232		1.321		0.167	0.107	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	4.093	6.990	17.119	11.656	7.805	6.699	24.720	93.432	23.181	9.374	5.711	2.623
TOTAL FLOW (cms days)	0.116	0.198	0.485	0.330	0.221	0.190	0.700	2.646	0.656	0.265	0.162	0.074
TOTAL DEPTH (in)	0.633	1.080	2.646	1.802	1.206	1.035	3.821	14.440	3.583	1.449	0.883	0.405
TOTAL DEPTH (cm)	1.607	2.744	6.720	4.576	3.064	2.630	9.704	36.679	9.100	3.680	2.242	1.030

ANNUAL SUMMARY:
Sum of Mean Daily Flow 213.403 cfs = 6.044 cms
Total Depth 32.983 in = 83.776 cm
Maximum Instantaneous Flow 6.550 cfs = 0.185 cms on May 10 at 22.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 214
WATERSHED AREA: 154 ACRES (62 HECTARES)

WATER YEAR 1977
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.062	0.115	0.066	0.058	0.048	0.071	0.064	1.040	0.361	0.135	0.057	0.071
2	0.102	0.086	0.066	0.058	0.048	0.071	0.064	1.022	0.345	0.152	0.055	0.062
3	0.104	0.079	0.067	0.058	0.048	0.071	0.064	0.918	0.329	0.141	0.054	0.056
4	0.082	0.075	0.064	0.058	0.048	0.071	0.095	0.810	0.315	0.148	0.051	0.051
5	0.077	0.073	0.061	0.058	0.048	0.071	0.135	0.735	0.298	0.140	0.051	0.050
6	0.076	0.069	0.057	0.058	0.048	0.071	0.163	0.690	0.283	0.134	0.049	0.047
7	0.073	0.066	0.061	0.058	0.048	0.068	0.263	0.687	0.280	0.124	0.048	0.044
8	0.068	0.066	0.069	0.058	0.048	0.067	0.434	0.672	0.327	0.117	0.046	0.044
9	0.065	0.066	0.072	0.058	0.048	0.065	0.434	0.636	0.272	0.115	0.045	0.042
10	0.089	0.064	0.073	0.058	0.048	0.064	0.357	0.644	0.257	0.111	0.045	0.041
11	0.103	0.062	0.073	0.056	0.047	0.064*	0.322	0.604	0.261	0.105	0.043	0.041
12	0.080	0.059	0.073	0.039	0.053	0.064*	0.346	0.558	0.250	0.103	0.043	0.040
13	0.073	0.056	0.072	0.040	0.066	0.067*	0.359	0.523	0.258	0.084	0.042	0.039
14	0.069	0.055	0.071	0.041	0.057	0.067*	0.335	0.498	0.243	0.081	0.041	0.038
15	0.066	0.059	0.067	0.042	0.054	0.067*	0.353	0.487	0.230	0.079	0.041	0.068
16	0.065	0.077	0.067	0.044	0.054	0.067*	0.362	0.483	0.216	0.076	0.040	0.096
17	0.064	0.081	0.067	0.059	0.056	0.067*	0.335	0.501	0.205	0.077	0.040	0.081
18	0.063	0.100	0.066	0.090	0.058	0.067*	0.335	0.513	0.196	0.112	0.039	0.058
19	0.063	0.075	0.062	0.072	0.062	0.067*	0.329	0.554	0.190	0.096	0.036*	0.058
20	0.063	0.069	0.060	0.061	0.070	0.067*	0.339	0.545	0.194	0.083	0.033*	0.108
21	0.062	0.066	0.058	0.059	0.076	0.067*	0.372	0.548	0.185	0.079	0.033	0.102
22	0.060	0.067	0.057	0.057	0.073	0.067*	0.496	0.531	0.175	0.077	0.040	0.083
23	0.058	0.066	0.058	0.056	0.072	0.067*	0.735	0.525	0.165	0.070	0.037	0.071
24	0.058	0.072	0.058	0.054	0.071	0.067*	1.072	0.512	0.157	0.106	0.053	0.072
25	0.089	0.081	0.058	0.053	0.069	0.067*	1.326	0.477	0.151	0.097	0.074	0.080
26	0.084	0.063*	0.061	0.053	0.069	0.067*	1.265	0.451	0.144	0.098	0.135	0.073
27	0.072	0.053*	0.063	0.052	0.069	0.067	1.085	0.439	0.139	0.074	0.104	0.066
28	0.070	0.048*	0.062	0.052	0.070	0.066	1.008	0.437	0.136	0.064	0.074	0.083
29	0.067	0.052	0.060	0.051		0.066	0.960	0.406	0.133	0.064	0.078	0.097
30	0.065	0.064	0.059	0.051		0.065	0.951	0.384	0.131	0.061	0.181	0.112
31	0.063		0.058	0.050		0.064		0.360		0.061	0.096	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	2.252	2.080	1.982	1.714	1.629	2.079	14.756	18.185	6.824	3.060	1.804	1.975
TOTAL FLOW (cms days)	0.064	0.059	0.056	0.049	0.046	0.059	0.418	0.515	0.193	0.087	0.051	0.056
TOTAL DEPTH (in)	0.348	0.321	0.306	0.265	0.252	0.321	2.281	2.811	1.055	0.473	0.279	0.305
TOTAL DEPTH (cm)	0.884	0.817	0.778	0.673	0.640	0.816	5.793	7.139	2.679	1.201	0.708	0.775

ANNUAL SUMMARY:
Sum of Mean Daily Flow 58.341 cfs = 1.652 cms
Total Depth 9.017 in = 22.903 cm
Maximum Instantaneous Flow 1.780 cfs = 0.050 cms on May 1 at 19.30 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 214
WATERSHED AREA: 154 ACRES (62 HECTARES)

WATER YEAR 1978
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.090	0.079	0.222	0.181*	0.132	0.167	2.617	1.972	1.064	0.300	0.159	0.093
2	0.079	0.118	1.033	0.177*	0.131	0.169	2.343	1.978	1.024	0.304	0.153	0.089
3	0.071	0.085	0.766	0.173*	0.131	0.169	1.975	1.890	0.973	0.325	0.146	0.085
4	0.066	0.082	0.559	0.169*	0.131	0.170	1.702	1.767	0.920	0.565	0.140	0.082
5	0.062	0.091	0.444	0.165	0.138	0.174	1.502	1.618	0.875	0.455	0.135	0.089
6	0.068	0.088	0.398	0.161	0.158	0.176	1.380	1.492	0.822	0.419	0.130	0.098
7	0.101	0.084	0.359	0.157	0.152	0.176	1.274	1.409	0.765	0.559	0.125	0.124
8	0.087	0.078	0.316	0.163	0.148	0.188	1.161	1.390	0.720	0.486	0.122	0.108
9	0.121	0.078*	0.284	0.161	0.147	0.223	1.087	1.437	0.695	0.450	0.121	0.092
10	0.095	0.079*	0.264	0.156	0.146	0.211	1.100	1.694	0.731	0.435	0.112	0.088
11	0.091	0.080*	0.259	0.154	0.144	0.210	1.208	1.840	0.651	0.411	0.110	0.117
12	0.088	0.079	0.251	0.153	0.143	0.209	1.156	1.771	0.595	0.383	0.117	0.167
13	0.080	0.084	0.278	0.152	0.139	0.209	1.108	1.810	0.561	0.354	0.169	0.119
14	0.075	0.089	0.380	0.153	0.138	0.211	1.057	1.885	0.528	0.334	0.137	0.111
15	0.071	0.115	0.441	0.154	0.137	0.209	1.070	1.953	0.503	0.331	0.162	0.100
16	0.067	0.098	0.440	0.153	0.135	0.209	1.064	1.863	0.469	0.314	0.186	0.095
17	0.064	0.090*	0.432	0.153	0.132	0.223	1.022	1.758	0.437	0.302	0.188	0.094
18	0.061	0.082*	0.405	0.150	0.131	0.257	1.012	1.634	0.430	0.285	0.150	0.098
19	0.057	0.077	0.364	0.150	0.132	0.299	1.048	1.603	0.406	0.267	0.133	0.098
20	0.056	0.079	0.328	0.148	0.142	0.363	1.070	1.570	0.380	0.255	0.125	0.091
21	0.055	0.080	0.310	0.146	0.144	0.467	1.037	1.561	0.359	0.243	0.118	0.086
22	0.053	0.080	0.293	0.145	0.144	0.616	0.994	1.581	0.346	0.233	0.209	0.084
23	0.053	0.075	0.272	0.140	0.145	0.795	0.938	1.466	0.333	0.223	0.150	0.082
24	0.052	0.071	0.256	0.138	0.152	0.860	0.906	1.434	0.380	0.214	0.129	0.079
25	0.132	0.263	0.241	0.137	0.160	0.833	1.067	1.392	0.472	0.201	0.120	0.077
26	0.110	0.228	0.231	0.137	0.162	0.856	1.332	1.341	0.367	0.189	0.114	0.074
27	0.082	0.166	0.222	0.134	0.163	1.058	1.543	1.309	0.331	0.182	0.108	0.073
28	0.075	0.148	0.212	0.134	0.165	1.411	1.609	1.302	0.311	0.228	0.101	0.076
29	0.073	0.200	0.207	0.134		1.811	1.596	1.255	0.369	0.193	0.097	0.075
30	0.078	0.170	0.198	0.133		2.176	1.736	1.174	0.320	0.176	0.096	0.072
31	0.076		0.187*	0.132		2.458		1.120		0.166	0.096	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	2.389	3.216	10.852	4.689	4.020	17.563	39.711	49.265	17.134	9.781	4.159	2.815
TOTAL FLOW (cms days)	0.068	0.091	0.307	0.133	0.114	0.497	1.125	1.395	0.485	0.277	0.118	0.080
TOTAL DEPTH (in)	0.369	0.497	1.677	0.725	0.621	2.714	6.138	7.614	2.648	1.512	0.643	0.435
TOTAL DEPTH (cm)	0.938	1.262	4.260	1.841	1.578	6.895	15.589	19.340	6.726	3.840	1.633	1.105

ANNUAL SUMMARY:
Sum of Mean Daily Flow 165.590 cfs = 4.690 cms
Total Depth 25.593 in = 65.006 cm
Maximum Instantaneous Flow 2.700 cfs = 0.076 cms on April 1 at 12.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 214
WATERSHED AREA: 154 ACRES (62 HECTARES)

WATER YEAR 1979
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.074	0.058	0.057	0.049	0.045	0.063	0.159	1.739	0.704	0.184	0.052	0.068
2	0.071	0.059	0.058	0.046	0.044	0.063	0.150	1.835	0.644	0.176	0.050	0.059
3	0.069	0.057	0.057	0.043	0.043	0.063	0.141	1.899	0.595	0.168	0.048	0.053
4	0.067	0.061	0.082	0.040	0.043	0.063	0.134	2.109	0.545	0.160	0.047	0.056
5	0.066	0.055	0.073	0.036	0.043	0.077	0.160	2.497	0.519	0.147	0.045	0.051
6	0.066	0.053	0.074	0.036	0.042	0.150	0.184	2.397	0.515	0.142	0.044	0.049
7	0.065	0.054	0.072	0.036	0.043	0.178	0.217	2.012	0.474	0.139	0.043	0.047
8	0.064	0.174	0.071	0.037	0.043	0.138	0.223	1.767	0.436	0.129	0.043	0.046
9	0.063	0.080	0.060	0.039	0.045	0.121	0.239	1.563	0.409	0.126	0.047	0.044
10	0.063	0.057	0.052	0.039	0.050	0.109	0.238	1.423	0.385	0.121	0.049	0.046
11	0.061	0.055	0.052	0.040	0.054	0.105	0.235	1.417	0.358	0.121	0.047	0.055
12	0.059	0.052	0.051	0.041	0.095	0.104	0.217	1.405	0.338	0.121*	0.049	0.048
13	0.060	0.053	0.051	0.042	0.160	0.105	0.208	1.510	0.324	0.118*	0.052	0.045
14	0.060	0.052	0.051	0.043	0.106	0.109	0.198	1.640	0.307	0.114*	0.055	0.044
15	0.060	0.051	0.050	0.043	0.084	0.123	0.194	1.902	0.292	0.111*	0.069	0.042
16	0.059	0.051	0.051	0.043	0.079	0.143	0.224	2.081	0.281	0.106*	0.055	0.040
17	0.058	0.051	0.050	0.043	0.075	0.147	0.323	2.083	0.285	0.096*	0.050	0.040
18	0.059	0.052	0.050	0.044	0.073	0.137	0.337	2.006	0.306	0.088	0.048	0.039
19	0.058	0.053	0.049	0.044	0.071	0.127	0.341	1.873	0.281	0.086	0.049	0.039
20	0.057	0.053	0.049	0.043	0.070	0.124	0.324	1.747	0.257	0.085	0.046	0.039
21	0.058	0.052	0.048	0.044	0.068	0.124	0.350	1.646	0.319	0.083	0.051*	0.039
22	0.058	0.052	0.049	0.044	0.067	0.124	0.332	1.582	0.258	0.092	0.046*	0.039
23	0.056	0.052	0.049	0.044	0.065	0.128	0.406	1.531	0.237	0.082	0.095*	0.034
24	0.055	0.052	0.049	0.044	0.065	0.146	0.476	1.469	0.222	0.070	0.059*	0.034
25	0.054	0.052	0.049	0.044	0.065	0.160	0.553	1.362	0.208	0.063	0.050*	0.034
26	0.054	0.052	0.049	0.045	0.064	0.158	0.673	1.240	0.197	0.061	0.048*	0.034
27	0.053	0.052	0.050	0.045	0.064	0.168	0.886	1.137	0.187	0.060	0.047*	0.031
28	0.053	0.052	0.049	0.045	0.064	0.194	1.197	1.051	0.179	0.066	0.045*	0.030
29	0.054	0.053	0.049	0.045		0.192	1.500	0.955	0.174	0.064	0.067*	0.030
30	0.055	0.053	0.049	0.045		0.185	1.674	0.855	0.183	0.057	0.115*	0.030
31	0.054		0.049	0.045		0.175		0.777		0.053	0.109	
MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	1.861	1.753	1.701	1.315	1.831	4.000	12.490	50.507	10.416	3.291	1.717	1.285
TOTAL FLOW (cms days)	0.053	0.050	0.048	0.037	0.052	0.113	0.354	1.430	0.295	0.093	0.049	0.036
TOTAL DEPTH (in)	0.288	0.271	0.263	0.203	0.283	0.618	1.930	7.806	1.610	0.509	0.265	0.199
TOTAL DEPTH (cm)	0.731	0.688	0.668	0.516	0.719	1.570	4.903	19.828	4.089	1.292	0.674	0.504

ANNUAL SUMMARY:
Sum of Mean Daily Flow 92.167 cfs = 2.610 cms
Total Depth 14.245 in = 36.182 cm
Maximum Instantaneous Flow 2.520 cfs = 0.071 cms on May 5 at 0.30 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 216
WATERSHED AREA: 54 ACRES (21 HECTARES)

WATER YEAR 1975
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.039	0.023	0.014*	0.014	0.013	0.014	0.019	0.030	0.900	0.415	0.115	0.076
2	0.039	0.024	0.014	0.014	0.013	0.018	0.019	0.041	1.122	0.387	0.107	0.073
3	0.039	0.023	0.012	0.014	0.013	0.019	0.019	0.055	1.350	0.363	0.103	0.069
4	0.038	0.021	0.011	0.014	0.013*	0.019	0.019	0.042	1.339	0.342	0.098	0.065
5	0.038	0.020	0.012	0.014	0.012*	0.019	0.019	0.039	1.385	0.321	0.094	0.062
6	0.037	0.024	0.012	0.013	0.011*	0.019	0.019	0.038	1.552	0.303	0.090	0.060
7	0.036	0.028	0.012	0.013	0.011*	0.019	0.019	0.046	1.622	0.287	0.108	0.058
8	0.035	0.020	0.010	0.012	0.010*	0.019	0.019	0.061	1.547	0.271	0.091	0.056
9	0.031	0.013	0.010	0.012	0.010*	0.019	0.019	0.084	1.417	0.258	0.087	0.054
10	0.029	0.013	0.013	0.012	0.009*	0.019	0.019	0.120	1.337	0.245	0.084	0.053
11	0.032	0.011	0.011	0.012	0.009*	0.020	0.021	0.174	1.331	0.232	0.081	0.051
12	0.029	0.017	0.011	0.013	0.008*	0.021	0.024	0.194	1.356	0.225	0.079	0.050
13	0.028	0.020	0.011	0.013	0.008*	0.020	0.026	0.214	1.365	0.264	0.078	0.049
14	0.027	0.013	0.010	0.013	0.007*	0.020	0.030	0.305	1.324	0.266	0.075	0.047
15	0.026	0.013	0.010	0.013	0.007*	0.020	0.035	0.411	1.273	0.210	0.070	0.046
16	0.025	0.012	0.015	0.013	0.007*	0.020	0.032	0.448	1.131	0.201	0.072	0.062
17	0.024	0.012	0.013	0.099	0.007*	0.020	0.028	0.460	1.056	0.189	0.083	0.062
18	0.025	0.015	0.012	0.078	0.007*	0.020	0.027	0.439	0.975	0.174	0.097	0.052
19	0.025	0.014	0.012	0.034	0.007*	0.020	0.027	0.389	0.926	0.165	0.094	0.049
20	0.024	0.014	0.013	0.023	0.007*	0.020	0.027	0.339	0.864	0.157	0.091	0.046
21	0.024	0.018	0.015	0.022	0.007*	0.020	0.028	0.341	0.753	0.154	0.082	0.045
22	0.029	0.019	0.014	0.022	0.007*	0.020	0.033	0.315	0.693	0.146	0.083	0.054
23	0.029	0.016	0.014	0.021	0.007*	0.020	0.034	0.386	0.656	0.141	0.152	0.043
24	0.026	0.016	0.014	0.019	0.007*	0.019	0.034	0.339	0.643	0.134	0.133	0.041
25	0.021	0.014	0.000	0.014	0.007*	0.019	0.037	0.313	0.578	0.128	0.102	0.040
26	0.026	0.015	0.014	0.013	0.007*	0.019	0.034	0.315	0.541	0.122	0.091	0.039
27	0.023	0.016	0.014	0.013	0.007*	0.019	0.032	0.334	0.509	0.116	.0.089	0.039
28	0.027	0.015*	0.014	0.013	0.010*	0.019	0.030	0.358	0.486	0.116	0.097	0.038
29	0.021	0.015*	0.014	0.013		0.019	0.031	0.426	0.464	0.116*	0.084	0.037
30	0.022	0.015*	0.014	0.013		0.019	0.031	0.510	0.436	0.124*	0.079	0.037
31	0.021		0.014	0.013		0.019		0.663		0.124*	0.076	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	0.893	0.506	0.375	0.618	0.251	0.589	0.789	8.227	30.925	6.696	2.862	1.551
TOTAL FLOW (cms days)	0.025	0.014	0.011	0.018	0.007	0.017	0.022	0.233	0.876	0.190	0.081	0.044
TOTAL DEPTH (in)	0.394	0.223	0.165	0.273	0.111	0.260	0.348	3.626	13.631	2.951	1.261	0.684
TOTAL DEPTH (cm)	1.000	0.567	0.420	0.692	0.281	0.660	0.883	9.210	34.623	7.496	3.204	1.737

ANNUAL SUMMARY:
Sum of Mean Daily Flow 54.283 cfs = 1.537 cms
Total Depth 23.927 in = 60.774 cm
Maximum Instantaneous Flow 1.710 cfs = 0.048 cms on June 6 at 16.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 216
WATERSHED AREA: 54 ACRES (21 HECTARES)

WATER YEAR 1976
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.036	0.069	0.224	0.145	0.105	0.081	0.073	0.290	0.796	0.292	0.127	0.066
2	0.035	0.080	0.157	0.109	0.105	0.079	0.070	0.332	0.710	0.278	0.110	0.066
3	0.034	0.090	0.143	0.108	0.104	0.078	0.073	0.434	0.655	0.265	0.124	0.065
4	0.057	0.091	0.152	0.105	0.101	0.077	0.082	0.589	0.607	0.255	0.108	0.064
5	0.043	0.100	0.145	0.103	0.101	0.077	0.100	0.641	0.574	0.244	0.102	0.063
6	0.047	0.104	0.137	0.101	0.101	0.077	0.094	0.734	0.546	0.232	0.097	0.095
7	0.059	0.101	0.187	0.100	0.101	0.077	0.108	0.820	0.522	0.223	0.216	0.070
8	0.052	0.099	0.219	0.098	0.101	0.077	0.139	0.964	0.505	0.217	0.165	0.066
9	0.047	0.094	0.199	0.096	0.101	0.075	0.136	1.184	0.486	0.209	0.141	0.063
10	0.044	0.091	0.197	0.093	0.099	0.074	0.150	1.441	0.474	0.200	0.128	0.061
11	0.055	0.086	0.197	0.093	0.096	0.075	0.173	1.626	0.435	0.200	0.117	0.067
12	0.059	0.083	0.193	0.092	0.094	0.074	0.186	1.678	0.424	0.232	0.111	0.064
13	0.059	0.079	0.186	0.090	0.093	0.073	0.189	1.725	0.404	0.189*	0.105	0.061
14	0.055	0.079	0.178	0.089	0.092	0.072	0.203	1.786	0.401	0.171*	0.100	0.059
15	0.056	0.085	0.172	0.162	0.091	0.072	0.202	1.730	0.377	0.169	0.127	0.057
16	0.053	0.078	0.164	0.147	0.090	0.072	0.199	1.674	0.460	0.159	0.105	0.060
17	0.050	0.080	0.159	0.131	0.089	0.074	0.199	1.571	0.446	0.161	0.095	0.060
18	0.056	0.064	0.153	0.127	0.088	0.075	0.198	1.472	0.417	0.169	0.093	0.060
19	0.056	0.061	0.149	0.123	0.088	0.073	0.196	1.410	0.412	0.153	0.092	0.057
20	0.061	0.063	0.144	0.120	0.088	0.071	0.193	1.319	0.406	0.147	0.089	0.053
21	0.137	0.062	0.140	0.120	0.087	0.070	0.193	1.252	0.428	0.151	0.086	0.052
22	0.088	0.061	0.138	0.119	0.086	0.070	0.191	1.223	0.416	0.137	0.084	0.054
23	0.080	0.061	0.134	0.117	0.085	0.070	0.195	1.207	0.392	0.128	0.091	0.063
24	0.075	0.077	0.132	0.116	0.084	0.070	0.212	1.218	0.375	0.144	0.083	0.057
25	0.072	0.067	0.130	0.115	0.083	0.070	0.199	1.200	0.366	0.129	0.109	0.054
26	0.071	0.065	0.135	0.114	0.083	0.069	0.193	1.133	0.350	0.119	0.094	0.052
27	0.067	0.064	0.126	0.113	0.085	0.069	0.185	1.131	0.335	0.114	0.085	0.051
28	0.064	0.062	0.121	0.111	0.084	0.068	0.185	1.043	0.321	0.110	0.079	0.050
29	0.072	0.060	0.125	0.110	~~0.080~~ 0.083	0.066	0.209	0.967	0.312	0.106	0.076	0.048
30	0.080	0.064	0.122	0.107		0.070	0.241	0.915	0.301	0.103	0.072	0.047
31	0.072		0.118	0.106		0.074		0.847		0.100	0.069	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	1.890	2.320	4.875	3.474	2.604	2.268	4.965	35.552	13.652	5.505	3.280	1.802
TOTAL FLOW (cms days)	0.054	0.066	0.138	0.098	0.074	0.064	0.141	1.007	0.387	0.156	0.093	0.051
TOTAL DEPTH (in)	0.833	1.022	2.149	1.531	1.148	1.000	2.188	15.670	6.017	2.426	1.446	0.794
TOTAL DEPTH (cm)	2.116	2.597	5.458	3.889	2.915	2.539	5.558	39.803	15.284	6.163	3.673	2.017

ANNUAL SUMMARY:
Sum of Mean Daily Flow 82.187 cfs = 2.328 cms
Total Depth 36.225 in = 92.013 cm
Maximum Instantaneous Flow 1.850 cfs = 0.052 cms on May 13 at 14.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 216
WATERSHED AREA: 54 ACRES (21 HECTARES)

WATER YEAR 1977
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.046	0.067	0.033	0.033	0.030	0.034	0.032	0.327	0.154	0.070	0.035	0.042
2	0.065	0.052	0.033	0.032	0.031	0.034	0.032	0.327	0.149	0.075	0.035	0.038
3	0.064	0.049	0.033	0.032	0.031	0.034	0.031	0.305	0.143	0.069	0.035	0.037
4	0.054	0.048	0.033	0.032	0.032	0.037	0.039	0.281	0.137	0.069	0.034	0.035
5	0.051	0.046	0.032	0.032	0.033	0.032	0.038	0.260	0.130	0.066	0.033	0.034
6	0.051	0.044	0.031	0.032	0.033	0.033	0.045	0.248	0.124	0.063	0.032	0.033
7	0.050	0.043	0.032	0.032	0.034	0.034	0.061	0.256	0.121	0.059	0.032	0.032
8	0.049	0.043	0.033	0.032	0.034	0.033	0.085	0.251	0.144	0.057	0.031	0.031
9	0.048	0.043	0.033	0.031	0.034	0.033	0.079	0.254	0.121	0.056	0.030	0.030
10	0.058	0.042	0.033	0.031	0.034	0.033	0.062	0.276	0.114	0.054	0.031	0.029
11	0.064	0.042	0.033	0.029	0.034	0.033	0.068	0.251	0.114	0.052	0.030	0.029
12	0.053	0.040	0.033	0.028	0.034	0.033	0.070	0.236	0.111	0.051	0.029	0.028
13	0.050	0.037	0.033	0.027	0.039	0.032	0.073	0.228	0.114	0.050	0.031	0.027
14	0.048	0.036	0.032	0.026	0.035	0.032	0.068	0.216	0.106	0.047	0.029	0.026
15	0.047	0.036	0.032	0.025	0.034	0.032	0.069	0.211	0.100	0.046	0.028	0.040
16	0.047	0.045	0.032	0.019	0.034	0.032	0.070	0.206	0.095	0.044	0.027	0.054
17	0.046	0.048	0.032	0.024	0.034	0.032	0.064	0.202	0.091	0.044	0.026	0.047
18	0.044	0.055	0.032	0.037	0.034	0.032	0.064	0.205	0.087	0.059	0.026	0.035
19	0.044	0.044	0.031	0.031	0.034	0.032	0.064	0.217	0.085	0.052	0.024	0.034
20	0.044	0.042	0.031	0.026	0.036	0.032	0.068	0.226	0.086	0.047	0.024	0.060
21	0.044	0.040	0.031	0.025	0.038	0.032	0.078	0.208	0.083	0.045	0.023	0.052
22	0.043	0.040	0.031	0.025	0.036	0.035	0.106	0.203	0.079	0.046	0.026	0.043
23	0.042	0.040	0.031	0.025	0.035	0.035	0.145	0.204	0.075	0.043	0.025	0.038
24	0.042	0.042	0.032	0.025	0.035	0.034	0.192	0.200	0.072	0.057	0.032	0.040
25	0.052	0.046	0.032	0.026	0.034	0.033	0.240	0.194	0.071	0.054	0.046	0.045
26	0.052	0.036*	0.032	0.026	0.034	0.033	0.243	0.198	0.068	0.052	0.080	0.041
27	0.046	0.033*	0.034	0.027	0.034	0.033	0.234	0.184	0.067	0.043	0.060	0.039
28	0.044	0.030	0.034	0.027	0.034	0.032	0.242	0.184	0.065	0.040	0.044	0.046
29	0.043	0.032	0.034	0.028		0.032	0.251	0.176	0.064	0.038	0.046	0.051
30	0.042	0.034	0.034	0.029		0.032	0.274	0.167	0.275	0.037	0.092	0.058
31	0.042		0.033	0.029		0.032		0.160		0.037	0.052	
MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	1.516	1.274	1.003	0.883	0.950	1.019	3.185	7.058	3.244	1.622	1.126	1.170
TOTAL FLOW (cms days)	0.043	0.036	0.028	0.025	0.027	0.029	0.090	0.200	0.092	0.046	0.032	0.033
TOTAL DEPTH (in)	0.668	0.562	0.442	0.389	0.419	0.449	1.404	3.111	1.430	0.715	0.496	0.516
TOTAL DEPTH (cm)	1.697	1.427	1.123	0.988	1.064	1.141	3.566	7.902	3.632	1.816	1.261	1.310

ANNUAL SUMMARY:
Sum of Mean Daily Flow 24.050 cfs = 0.681 cms
Total Depth 10.601 in = 26.925 cm
Maximum Instantaneous Flow 0.640 cfs = 0.018 cms on May 1 at 21.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 216
WATERSHED AREA: 54 ACRES (21 HECTARES)

WATER YEAR 1978
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.049	0.035	0.068	0.066	0.045	0.044	0.460	0.605	0.663	0.196	0.092	0.058
2	0.044	0.048	0.265	0.065	0.044	0.043	0.479	0.625	0.656	0.202	0.089	0.057
3	0.041	0.035	0.181	0.062	0.045	0.043	0.468	0.683	0.646	0.194	0.086	0.055
4	0.039	0.034	0.160	0.060	0.045	0.042	0.445	0.671	0.635	0.288	0.085	0.051
5	0.034	0.037	0.142	0.060	0.045	0.043	0.409	0.640	0.618	0.224	0.082	0.055
6	0.032	0.037	0.131	0.059	0.050	0.042	0.382	0.622	0.599	0.205	0.080	0.059
7	0.046	0.036	0.123	0.057	0.050	0.042	0.361	0.605	0.571	0.230	0.078	0.069
8	0.040	0.034	0.112	0.057	0.049	0.046	0.336	0.605	0.542	0.204	0.076	0.061
9	0.052	0.034	0.105	0.058	0.048	0.055	0.318	0.613	0.522	0.190	0.074	0.054
10	0.041	0.035	0.099	0.056	0.047	0.049	0.324	0.715	0.531	0.187	0.073	0.054
11	0.040	0.034	0.098	0.053	0.046	0.048	0.348	0.740	0.490	0.170	0.074	0.070
12	0.040	0.034	0.094	0.051	0.045	0.047	0.315	0.751	0.460	0.161	0.081	0.092
13	0.038	0.035	0.100	0.052	0.044	0.046	0.307	0.821	0.438	0.158	0.103	0.068
14	0.036	0.038	0.137	0.053	0.044	0.045	0.308	0.864	0.411	0.153	0.085	0.062
15	0.034	0.050	0.130	0.053	0.043	0.044	0.323	0.911	0.393	0.158	0.098	0.059
16	0.033	0.040	0.116	0.054	0.043	0.044	0.324	0.908	0.373	0.155	0.104	0.056
17	0.032	0.036	0.110	0.053	0.042	0.046	0.306	0.896	0.352	0.150	0.106	0.057
18	0.030	0.031	0.106	0.053	0.041	0.054	0.303	0.867	0.345	0.147	0.087	0.058
19	0.029	0.029	0.102	0.052	0.040	0.061	0.313	0.867	0.328	0.142	0.081	0.056
20	0.028	0.030*	0.096	0.052	0.042	0.063	0.317	0.855	0.314	0.136	0.077	0.054
21	0.028	0.030*	0.093	0.052	0.043	0.068	0.301	0.880	0.300	0.127	0.074	0.050
22	0.027	0.030*	0.092	0.052	0.042	0.080	0.291	0.891	0.289	0.121	0.114	0.049
23	0.027	0.030*	0.089	0.050	0.043	0.091	0.286	0.846	0.284	0.118	0.083	0.048
24	0.026	0.030*	0.086	0.048	0.043	0.091	0.287	0.834	0.305	0.116	0.075	0.047
25	0.061	0.091	0.083	0.048	0.043	0.095	0.327	0.793	0.355	0.113	0.070	0.046
26	0.048	0.074	0.080	0.048	0.044	0.119	0.374	0.747	0.294	0.114	0.069	0.045
27	0.035	0.056	0.077	0.048	0.045	0.147	0.393	0.734	0.277	0.107	0.068	0.044
28	0.033	0.053	0.075	0.048	0.045	0.182	0.414	0.738	0.265	0.117	0.065	0.046
29	0.033	0.069	0.073	0.047		0.234	0.441	0.702	0.245	0.105	0.064	0.044
30	0.033	0.058	0.071	0.046		0.296	0.510	0.675	0.200	0.099	0.063	0.043
31	0.033		0.069	0.045		0.388		0.667		0.097	0.062	
MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	1.144	1.243	3.361	1.657	1.244	2.739	10.766	23.369	12.701	4.881	2.520	1.668
TOTAL FLOW (cms days)	0.032	0.035	0.095	0.047	0.035	0.078	0.305	0.662	0.360	0.138	0.071	0.047
TOTAL DEPTH (in)	0.504	0.548	1.481	0.730	0.548	1.207	4.745	10.300	5.598	2.151	1.111	0.735
TOTAL DEPTH (cm)	1.281	1.391	3.762	1.855	1.393	3.066	12.053	26.163	14.219	5.464	2.821	1.867

ANNUAL SUMMARY:
Sum of Mean Daily Flow 67.291 cfs = 1.906 cms
Total Depth 29.660 in = 75.336 cm
Maximum Instantaneous Flow 0.960 cfs = 0.027 cms on May 22 at 4.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 218
WATERSHED AREA: 213 ACRES (86 HECTARES)

WATER YEAR 1975
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.324	0.316	0.234*	0.207	0.214	0.199*	0.191	0.210	2.330	2.336	0.749	0.613
2	0.318	0.308	0.234*	0.207	0.211	0.210*	0.190	0.257	2.658	2.217	0.716	0.584
3	0.320	0.301	0.234*	0.207	0.208	0.203*	0.189	0.329	2.985	2.077	0.694	0.557
4	0.324	0.294	0.232	0.207	0.212*	0.203*	0.187	0.264	2.803	1.934	0.676	0.540
5	0.326	0.295	0.229	0.205	0.212*	0.201*	0.187	0.236	3.174	1.804	0.656	0.526
6	0.326	0.315	0.229	0.204	0.209*	0.201*	0.187	0.226	3.704	1.699	0.639	0.513
7	0.326	0.330	0.231	0.204	0.207*	0.201*	0.187	0.240	3.718	1.599	0.784	0.497
8	0.319	0.289	0.224	0.204	0.205*	0.200*	0.185	0.380	3.564	1.505	0.645	0.486
9	0.315	0.254	0.224	0.203	0.202*	0.200*	0.184	0.493	3.372	1.419	0.618	0.476
10	0.311	0.250	0.224	0.201	0.199*	0.200*	0.185	0.654	3.394	1.344	0.598	0.471
11	0.344	0.244	0.229	0.200	0.195*	0.202*	0.193	0.770	3.648	1.286	0.583	0.462
12	0.324	0.304	0.223	0.198	0.193*	0.204	0.210	0.900	3.986	1.259	0.571	0.455
13	0.315	0.322	0.220	0.200	0.193*	0.203	0.224	0.883	3.988	1.341	0.559	0.449
14	0.311	0.261	0.220	0.201	0.190*	0.198	0.239	1.216	4.062	1.232	0.550	0.439
15	0.307	0.250	0.219	0.201	0.188*	0.201	0.280	1.512	4.414	1.181	0.538	0.439
16	0.302	0.238	0.254	0.201	0.186*	0.201	0.269	1.395	4.149	1.139	0.539	0.548
17	0.298	0.241	0.236	0.811	0.183*	0.201	0.230	1.325	3.785	1.076	0.618	0.602
18	0.294	0.248	0.224	0.821	0.181*	0.205	0.217	1.243	3.569	1.027	0.770	0.482
19	0.293	0.242	0.222	0.363	0.180*	0.206	0.213	1.049	3.508	0.993	0.729	0.456
20	0.299	0.250	0.238	0.315	0.180*	0.203	0.214	0.869	4.066	0.969	0.693	0.437
21	0.326	0.295	0.261	0.302	0.178*	0.201	0.218	0.920	3.689	0.949	0.592	0.427
22	0.342	0.285	0.237	0.293	0.178*	0.200	0.238	0.894	3.542	0.907	0.616	0.416
23	0.331	0.251	0.222	0.286	0.176*	0.200	0.261	1.318	3.550	0.877	1.143	0.411
24	0.325	0.255	0.219	0.278	0.175*	0.198	0.227	1.003	3.698	0.849	0.966	0.404
25	0.325	0.250	0.219	0.261	0.173*	0.199	0.244	0.855	3.411	0.823	0.682	0.396
26	0.309	0.235	0.215	0.232	0.171*	0.198	0.225	0.870	3.134	0.804	0.619	0.392
27	0.310	0.234	0.214	0.221	0.169*	0.195	0.215	1.023	2.958	0.782	0.603	0.387
28	0.307	0.234*	0.210	0.220	0.183*	0.194	0.208	1.145	2.635	0.808	0.731	0.379
29	0.300	0.234*	0.209	0.219		0.193	0.209	1.394	2.432	0.932	0.646	0.377
30	0.295	0.234*	0.210	0.216		0.193	0.210	1.646	2.407	0.810	0.610	0.375
31	0.301		0.208	0.216		0.193		1.947		0.793	0.622	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	9.765	8.056	7.002	8.302	5.348	6.208	6.413	27.463	102.333	38.770	20.752	13.991
TOTAL FLOW (cms days)	0.277	0.228	0.198	0.235	0.151	0.176	0.182	0.778	2.898	1.098	0.588	0.396
TOTAL DEPTH (in)	1.091	0.900	0.782	0.928	0.598	0.694	0.717	3.069	11.435	4.332	2.319	1.563
TOTAL DEPTH (cm)	2.772	2.286	1.988	2.356	1.518	1.762	1.820	7.795	29.045	11.004	5.890	3.971

ANNUAL SUMMARY:
Sum of Mean Daily Flow 254.403 cfs = 7.205 cms
Total Depth 28.428 in = 72.208 cm
Maximum Instantaneous Flow 4.720 cfs = 0.134 cms on June 15 at 17.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 218
WATERSHED AREA: 213 ACRES (86 HECTARES)

WATER YEAR 1976
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.370*	0.537*	0.417	0.588	0.532	0.406*	0.396*	1.067*	3.482	1.578	0.904	0.505
2	0.365*	0.595*	0.773	0.572	0.530	0.402*	0.383*	1.133*	3.422	1.516	0.788	0.491
3	0.360*	0.625*	0.793	0.572	0.521	0.401*	0.395*	1.781*	3.160	1.458	0.880	0.489
4	0.539*	0.606*	0.840	0.572	0.502	0.399*	0.437*	3.557*	3.071	1.408	0.757	0.479
5	0.404*	0.627*	0.729	0.565	0.500	0.398*	0.529*	3.796*	3.157	1.362	0.712	0.478
6	0.445*	0.606*	0.697	0.550	0.500	0.396*	0.493*	3.562*	3.189	1.316	0.694	0.694
7	0.554*	0.569*	0.844	0.551	0.500	0.393*	0.552*	3.158*	3.284	1.279	1.177	0.517
8	0.503*	0.537	1.187	0.567	0.505	0.391*	0.704*	2.827*	3.345	1.240	0.967	0.489
9	0.448*	0.512	0.920	0.544	0.501	0.390*	0.619*	2.764*	3.250	1.197	0.814	0.474
10	0.416*	0.516	0.876	0.539	0.495	0.394*	0.649*	3.450	3.152	1.164	0.735	0.465
11	0.517*	0.497	0.845	0.536	0.494	0.382*	0.748*	3.388	2.885	1.188	0.703	0.519
12	0.563*	0.485	0.820	0.530	0.492	0.383*	0.740*	3.330	2.863	1.501	0.702	0.489
13	0.556*	0.491	0.796	0.524	0.488	0.383*	0.687*	3.751	2.589	1.152	0.673	0.462
14	0.495*	0.501	0.775	0.551	0.483	0.382*	0.691*	3.962	2.603	1.088	0.661	0.449
15	0.505*	0.567	0.762	0.996	0.482	0.379*	0.649*	3.724	2.460	1.045	0.854	0.440
16	0.455*	0.514	0.739	0.813	0.477	0.382*	0.619*	3.870	3.341	1.010	0.703	0.462
17	0.428*	0.731	0.723	0.677	0.474	0.394*	0.603*	3.870	3.025	1.011	0.648	0.453
18	0.501*	0.920	0.710	0.638	0.472	0.395*	0.588*	3.719	2.664	1.095	0.666	0.457
19	0.508*	0.456	0.697	0.616	0.469	0.386*	0.578*	3.801	2.561	0.980	0.633	0.432
20	0.548*	0.452	0.684	0.601	0.465	0.386*	0.576*	3.811	2.568	0.955	0.625	0.421
21	1.193*	0.451	0.671	0.594	0.463	0.377*	0.572*	3.808	2.611	0.952	0.605	0.413
22	0.668*	0.448	0.657	0.585	0.462	0.391*	0.564*	3.912	2.467	0.898	0.609	0.427
23	0.595*	0.440	0.646	0.576	0.462	0.387*	0.593*	4.010	2.210	0.868	0.677	0.488
24	0.556*	0.566	0.645	0.570	0.420*	0.383*	0.696*	4.226	2.093	0.962	0.595	0.431
25	0.549*	0.470	0.631	0.560	0.407*	0.376*	0.625*	4.416	2.018	0.862	0.776	0.413
26	0.530*	0.462	0.643	0.556	0.409*	0.374*	0.592*	4.166	1.911	0.825	0.651	0.401
27	0.508*	0.440	0.615	0.555	0.424*	0.372*	0.575*	4.487	1.826	0.794	0.590	0.395
28	0.497*	0.428	0.602	0.549	0.419*	0.370*	0.587*	4.005	1.751	0.776	0.562	0.389
29	0.566*	0.419	0.650	0.546	0.410	0.366*	0.695*	3.879	1.687	0.756	0.547	0.382
30	0.636*	0.417	0.619	0.537		0.399*	0.858*	3.812	1.623	0.741	0.535	0.377
31	0.560*		0.638	0.535		0.411*		3.739		0.729	0.521	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	16.334	15.883	22.642	18.266	13.757	12.026	17.987	108.778	80.264	33.705	21.960	13.779
TOTAL FLOW (cms days)	0.463	0.450	0.641	0.517	0.390	0.341	0.509	3.081	2.273	0.955	0.622	0.390
TOTAL DEPTH (in)	1.825	1.775	2.530	2.041	1.537	1.344	2.010	12.155	8.969	3.766	2.454	1.540
TOTAL DEPTH (cm)	4.636	4.508	6.426	5.185	3.905	3.413	5.105	30.875	22.781	9.566	6.233	3.911

ANNUAL SUMMARY:
Sum of Mean Daily Flow 375.381 cfs = 10.631 cms
Total Depth 41.947 in = 106.545 cm
Maximum Instantaneous Flow 5.410 cfs = 0.153 cms on May 27 at 12.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 218
WATERSHED AREA: 213 ACRES (86 HECTARES)

WATER YEAR 1977
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.376	0.565	0.295	0.264	0.248	0.235	0.219	1.558	0.729	0.371	0.260	0.306
2	0.562	0.426	0.298	0.258	0.248	0.232	0.219	1.562	0.688	0.413	0.255	0.279
3	0.507	0.393	0.295	0.260	0.246	0.231	0.216	1.251	0.644	0.379	0.252	0.264
4	0.423	0.376	0.288	0.260	0.244	0.230	0.261	1.058	0.615	0.401	0.247	0.255
5	0.408	0.364	0.279	0.258	0.243	0.229	0.297	0.928	0.588	0.379	0.245	0.250
6	0.404	0.354	0.277	0.257	0.242	0.234	0.354	0.873	0.563	0.362	0.241	0.245
7	0.388	0.349	0.292	0.257	0.239	0.238	0.445	1.003	0.557	0.340	0.235	0.238
8	0.377	0.352	0.299	0.257	0.239	0.232	0.571	1.071	0.700	0.329	0.233	0.232
9	0.369	0.352	0.298	0.257	0.239	0.233	0.441	1.161	0.553	0.325	0.230	0.231
10	0.430	0.342	0.296	0.257	0.239	0.229	0.341	1.293	0.521	0.316	0.228	0.228
11	0.517	0.338	0.295	0.255	0.237	0.229	0.344	1.089	0.545	0.312	0.225	0.225
12	0.406	0.327	0.294	0.256	0.239	0.231	0.404	1.069	0.536	0.311	0.222	0.221
13	0.387	0.321	0.292	0.257	0.271	0.229	0.407	1.134	0.572	0.304	0.219	0.219
14	0.372	0.316	0.287	0.257	0.252	0.220	0.371	0.994	0.527	0.299	0.221	0.217
15	0.364	0.321	0.284	0.256	0.245	0.220	0.366	0.924	0.493	0.294	0.216	0.283
16	0.361	0.381	0.285	0.258	0.242	0.220	0.394	0.858	0.467	0.288	0.213	0.505
17	0.358	0.401	0.285	0.282	0.242	0.219	0.364	0.834	0.452	0.292	0.211	0.393
18	0.353	0.474	0.281	0.362	0.245	0.219	0.352	0.891	0.439	0.408	0.208	0.274
19	0.352	0.364	0.276	0.329	0.249	0.219	0.348	0.970	0.435	0.327	0.206	0.264
20	0.352	0.340	0.271	0.278	0.255	0.220	0.355	0.963	0.446	0.303	0.204	0.480
21	0.350	0.328	0.270	0.268	0.267	0.220	0.411	0.943	0.426	0.300	0.207	0.438
22	0.345	0.340	0.270	0.263	0.252	0.244	0.580	0.925	0.411	0.299	0.230	0.357
23	0.342	0.326	0.272	0.258	0.246	0.241	0.807	0.967	0.398	0.282	0.210	0.304
24	0.341	0.346	0.272	0.257	0.242	0.234	0.987	0.911	0.388	0.387	0.263	0.309
25	0.414	0.362	0.273	0.254	0.236	0.227	1.119	0.853	0.380	0.363	0.350	0.349
26	0.417	0.313*	0.282	0.251	0.234	0.227	1.063	0.824	0.370	0.346	0.660	0.322
27	0.372	0.304*	0.280	0.251	0.234	0.227	0.957	0.793	0.365	0.293	0.487	0.289
28	0.359	0.295	0.274	0.249	0.234	0.224	1.019	0.782	0.359	0.280	0.342	0.339
29	0.360	0.292	0.272	0.249		0.221	1.103	0.739	0.353	0.272	0.361	0.391
30	0.351	0.296	0.269	0.249		0.220	1.279	0.725	0.347	0.267	0.741	0.433
31	0.348		0.267	0.248		0.220		0.737		0.264	0.385	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	12.065	10.657	8.765	8.168	6.844	7.053	16.391	30.683	14.865	10.104	8.806	9.138
TOTAL FLOW (cms days)	0.342	0.302	0.248	0.231	0.194	0.200	0.464	0.869	0.421	0.286	0.249	0.259
TOTAL DEPTH (in)	1.348	1.191	0.979	0.913	0.765	0.788	1.832	3.429	1.661	1.129	0.984	1.021
TOTAL DEPTH (cm)	3.424	3.025	2.488	2.318	1.942	2.002	4.652	8.709	4.219	2.868	2.499	2.594

ANNUAL SUMMARY:
Sum of Mean Daily Flow 143.539 cfs = 4.065 cms
Total Depth 16.040 in = 40.741 cm
Maximum Instantaneous Flow 3.340 cfs = 0.095 cms on May 1 at 19.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 218
WATERSHED AREA: 213 ACRES (86 HECTARES)

WATER YEAR 1978
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.363	0.296	0.446	0.385	0.312	0.295	1.193	2.014	2.605	1.143	0.635	0.468
2	0.315	0.404	1.805	0.384	0.310	0.296	1.104	1.773	2.756	1.184	0.619	0.448
3	0.294	0.297	0.872	0.386	0.316	0.295	1.004	1.755	2.862	1.135	0.609	0.438
4	0.280	0.290	0.709	0.385	0.313	0.291	0.958	1.659	2.927	2.018	0.599	0.432
5	0.274	0.304	0.628	0.380	0.323	0.294	0.918	1.564	2.958	1.367	0.582	0.457
6	0.277	0.302	0.588	0.377	0.346	0.296	0.905	1.518	2.856	1.222	0.567	0.481
7	0.386	0.291	0.561	0.370	0.334	0.296	0.899	1.550	2.712	1.350	0.557	0.556
8	0.364	0.277*	0.524	0.373	0.322	0.313	0.846	1.649	2.612	1.254	0.549	0.496
9	0.462	0.277*	0.498	0.375	0.315	0.356	0.823	1.735	2.555	1.145	0.540	0.447
10	0.350	0.284	0.484	0.369	0.312	0.324	0.861	2.253	2.588	1.129	0.528	0.444
11	0.331	0.281	0.491	0.359	0.311	0.315	0.988	2.194	2.296	1.076	0.517	0.548
12	0.341	0.280	0.483	0.355	0.307	0.306	0.854	2.085	2.121	1.026	0.523	0.744
13	0.324	0.281	0.553	0.353	0.306	0.302	0.825	2.351	2.020	0.989	0.784	0.531
14	0.300	0.289	0.832	0.352	0.306	0.297	0.805	2.500	1.929	0.957	0.626	0.500
15	0.288	0.408	0.717	0.351	0.305	0.296	0.873	2.646	1.873	0.962	0.677	0.477
16	0.278	0.326	0.586	0.346	0.299	0.307	0.907	2.464	1.758	0.953	0.771	0.459
17	0.274	0.294*	0.545	0.343	0.295	0.318	0.836	2.413	1.684	0.923	0.795	0.452
18	0.269	0.270*	0.520	0.341	0.293	0.338	0.827	2.375	1.702	0.888	0.629	0.465
19	0.262	0.255*	0.498	0.342	0.296	0.372	0.884	2.588	1.592	0.860	0.574	0.459
20	0.258	0.257	0.486	0.335	0.312	0.388	0.924	2.656	1.508	0.846	0.551	0.438
21	0.253	0.258	0.468	0.334	0.310	0.413	0.858	2.893	1.455	0.815	0.538	0.423
22	0.251	0.258	0.472	0.330	0.306	0.465	0.824	2.927	1.420	0.788	0.822	0.410
23	0.250	0.258	0.463	0.327	0.303	0.499	0.805	2.641	1.364	0.770	0.614	0.402
24	0.246	0.258	0.453	0.325	0.304	0.473	0.808	2.573	1.489	0.747	0.543	0.396
25	0.524	0.754	0.445	0.323	0.307	0.452	0.988	2.426	1.870	0.721	0.518	0.391
26	0.454	0.695	0.440	0.321	0.307	0.533	1.246	2.338	1.429	0.706	0.508	0.382
27	0.312	0.398	0.431	0.319	0.303	0.647	1.271	2.465	1.321	0.694	0.496	0.376
28	0.294	0.362	0.423	0.317	0.297	0.727	1.269	2.774	1.264	0.752	0.486	0.392
29	0.291	0.502	0.418	0.312		0.843	1.294	2.500	1.221	0.705	0.474	0.382
30	0.295	0.403	0.411	0.313		0.936	1.545	2.371	1.190	0.666	0.480	0.383
31	0.290		0.397	0.312		1.161		2.457		0.650	0.481	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	9.748	10.108	17.648	10.792	8.668	13.440	29.142	70.109	59.933	30.443	18.194	13.675
TOTAL FLOW (cms days)	0.276	0.286	0.500	0.306	0.245	0.381	0.825	1.985	1.697	0.862	0.515	0.387
TOTAL DEPTH (in)	1.089	1.130	1.972	1.206	0.969	1.502	3.256	7.834	6.697	3.402	2.033	1.528
TOTAL DEPTH (cm)	2.767	2.869	5.009	3.063	2.460	3.815	8.271	19.899	17.011	8.641	5.164	3.881

ANNUAL SUMMARY:
Sum of Mean Daily Flow 291.899 cfs = 8.267 cms
Total Depth 32.618 in = 82.850 cm
Maximum Instantaneous Flow 4.120 cfs = 0.117 cms on July 4 at 14.30 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 225
WATERSHED AREA: 78 ACRES (31 HECTARES)

WATER YEAR 1979
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.034	0.019	0.019	0.019	0.019	0.035	0.045	0.291	0.279*	0.141	0.040	0.030
2	0.034	0.023	0.019	0.019	0.019	0.036	0.045	0.322	0.276*	0.132	0.039	0.025
3	0.032	0.025	0.019	0.019	0.019	0.038	0.045	0.351	0.269*	0.128	0.038	0.024
4	0.031	0.025	0.027	0.019	0.019	0.041	0.046	0.427	0.263*	0.121	0.037	0.024
5	0.029	0.020	0.019	0.019	0.019	0.041	0.055	0.576*	0.265*	0.112	0.035	0.022
6	0.029	0.019	0.019	0.019	0.019	0.070	0.063	0.547*	0.278*	0.108	0.034	0.021
7	0.028	0.020	0.019	0.019	0.019	0.063	0.070	0.433*	0.241*	0.104	0.033	0.019
8	0.027	0.076	0.019	0.019	0.020	0.050	0.061	0.359*	0.216*	0.097	0.032	0.018
9	0.027	0.030	0.019	0.019	0.021	0.052	0.064	0.291*	0.202*	0.094	0.030	0.019
10	0.027	0.024	0.019	0.019	0.021	0.051	0.059	0.259*	0.200*	0.091	0.028	0.025
11	0.025	0.022	0.019	0.019	0.021	0.051	0.058	0.257*	0.199*	0.089	0.028	0.020
12	0.024	0.021	0.019	0.019	0.034	0.051	0.056	0.266*	0.201*	0.086	0.029	0.018
13	0.024	0.019	0.019	0.019	0.049	0.051	0.056	0.328*	0.206*	0.078	0.030	0.017
14	0.024	0.019	0.019	0.019	0.035	0.051	0.055	0.428*	0.211*	0.075	0.031	0.016
15	0.023	0.019	0.019	0.019	0.031	0.051	0.058	0.620*	0.202	0.071	0.047	0.016
16	0.023	0.018	0.019	0.019	0.032	0.051	0.073	0.852*	0.189	0.068	0.033	0.015
17	0.023	0.018	0.019	0.019	0.032	0.051	0.107	0.865*	0.185	0.065	0.028	0.015
18	0.024	0.018	0.019	0.019	0.032	0.050	0.082	0.804*	0.188	0.063	0.027	0.015
19	0.024	0.018	0.019	0.019	0.032	0.049	0.072	0.770*	0.166	0.061	0.026	0.014
20	0.023	0.019	0.019	0.019	0.032	0.047	0.069	0.740*	0.187	0.058	0.025	0.014
21	0.024	0.019	0.019	0.019	0.032	0.047	0.068	0.743*	0.256	0.057	0.030	0.013
22	0.023	0.019	0.019	0.019	0.032	0.046	0.095	0.798*	0.205	0.062	0.026	0.013
23	0.023	0.019	0.019	0.019	0.032	0.045	0.102	0.842*	0.189	0.055	0.053	0.013
24	0.022	0.019	0.019	0.019	0.033	0.046	0.101	0.808*	0.179	0.052	0.035	0.013
25	0.022	0.019	0.019	0.019	0.033	0.048	0.105	0.679*	0.169	0.051	0.026	0.013
26	0.021	0.019	0.019	0.019	0.034	0.046	0.126	0.584*	0.158	0.049	0.024	0.013
27	0.021	0.019	0.019	0.019	0.034	0.046	0.164	0.495*	0.153	0.048	0.025	0.013
28	0.021	0.019	0.019	0.019	0.034	0.052	0.204	0.420*	0.145	0.051	0.024	0.013
29	0.022	0.019	0.019	0.019		0.051	0.243	0.356*	0.140	0.047	0.029	0.013
30	0.021	0.019	0.019	0.019		0.049	0.273	0.314*	0.142	0.043	0.055	0.013
31	0.021		0.019	0.019		0.047		0.293*		0.041	0.044	

MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	0.774	0.659	0.585	0.581	0.788	1.503	2.719	16.117	6.159	2.397	1.016	0.518
TOTAL FLOW (cms days)	0.022	0.019	0.017	0.016	0.022	0.043	0.077	0.456	0.174	0.068	0.029	0.015
TOTAL DEPTH (in)	0.236	0.201	0.179	0.177	0.240	0.458	0.830	4.918	1.880	0.732	0.310	0.158
TOTAL DEPTH (cm)	0.600	0.511	0.454	0.450	0.610	1.165	2.108	12.492	4.774	1.858	0.788	0.402

ANNUAL SUMMARY:
Sum of Mean Daily Flow 33.816 cfs = 0.958 cms
Total Depth 10.319 in = 26.210 cm
Maximum Instantaneous Flow 1.070 cfs = 0.030 cms on May 23 at 24.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 225
WATERSHED AREA: 78 ACRES (31 HECTARES)

WATER YEAR 1980
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.013	0.014	0.011	0.010	0.017	0.014	0.013	0.447	0.397	0.308	0.121	0.054
2	0.011	0.011	0.013	0.010	0.014	0.014	0.013	0.573	0.421	0.351	0.111	0.080
3	0.010	0.012	0.022	0.010	0.015	0.014	0.015	0.596	0.409	0.334	0.107	0.056
4	0.010	0.012	0.020	0.010	0.013	0.013	0.016	0.616	0.431	0.321	0.102	0.049
5	0.010	0.014	0.015	0.010	0.012	0.013	0.017	0.652	0.431	0.296	0.102	0.046
6	0.010	0.015	0.013	0.010	0.011	0.012	0.018	0.656	0.453	0.285	0.097	0.045
7	0.009	0.013	0.013	0.010	0.011	0.011	0.017	0.634	0.435	0.271	0.094	0.045
8	0.009	0.012	0.014	0.009	0.011	0.011	0.018	0.647	0.425	0.242	0.090	0.044
9	0.010	0.012	0.014	0.009	0.011	0.011	0.019	0.635	0.441	0.286	0.087	0.042
10	0.010	0.011	0.019	0.009	0.011	0.011	0.020	0.615	0.421	0.249	0.084	0.057
11	0.010	0.010	0.013	0.009	0.011	0.011	0.020	0.588	0.470	0.231	0.082	0.064
12	0.010	0.009	0.012	0.017	0.010	0.011	0.021	0.551	0.476	0.224	0.080	0.046
13	0.010	0.008	0.012	0.020	0.009	0.010	0.039	0.531	0.445	0.217	0.074	0.059
14	0.011	0.008	0.012	0.031	0.009	0.011	0.053	0.501	0.450	0.243	0.071	0.050
15	0.026	0.008	0.011	0.017	0.009	0.010	0.047	0.496	0.448	0.218	0.071	0.044
16	0.017	0.008	0.011	0.014	0.009	0.011	0.058	0.467	0.426	0.204	0.069	0.041
17	0.023	0.019	0.026	0.014	0.009	0.011	0.107	0.440	0.417	0.196	0.068	0.040
18	0.029	0.014	0.021	0.013	0.013	0.011	0.133	0.410	0.409	0.191	0.135	0.061
19	0.051	0.011	0.014	0.014	0.015	0.011	0.164	0.388	0.399	0.185	0.075	0.052
20	0.021	0.011	0.013	0.014	0.016	0.011	0.204	0.362	0.390	0.179	0.070	0.111
21	0.019	0.011	0.012	0.014	0.013	0.011	0.193	0.342	0.380	0.172	0.066	0.080
22	0.018	0.011	0.011	0.014	0.011	0.011	0.249	0.343	0.392	0.166	0.063	0.056
23	0.031	0.011	0.011	0.013	0.011	0.011	0.261	0.331	0.368	0.159	0.060	0.051
24	0.026	0.011	0.011	0.013	0.011	0.011	0.296	0.317	0.351	0.153	0.058	0.048
25	0.022	0.011	0.011	0.012	0.011	0.011	0.279	0.341	0.335	0.148	0.056	0.045
26	0.020	0.011	0.011	0.012	0.012	0.012	0.332	0.345	0.355	0.143	0.052	0.043
27	0.017	0.011	0.011	0.012	0.018	0.012	0.375	0.345	0.337	0.138	0.054	0.041
28	0.016	0.011	0.011	0.015	0.024	0.012	0.417	0.345	0.304	0.132	0.052	0.039
29	0.017	0.011	0.011	0.016	0.018	0.012	0.412	0.335	0.287	0.127	0.050	0.037
30	0.016	0.011	0.011	0.017		0.012	0.383	0.386	0.275	0.124	0.048	0.035
31	0.014		0.010	0.017		0.012		0.359		0.123	0.061	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	0.523	0.340	0.419	0.417	0.362	0.355	4.208	14.591	11.979	6.616	2.411	1.559
TOTAL FLOW (cms days)	0.015	0.010	0.012	0.012	0.010	0.010	0.119	0.413	0.339	0.187	0.068	0.044
TOTAL DEPTH (in)	0.160	0.104	0.128	0.127	0.110	0.108	1.284	4.452	3.655	2.019	0.736	0.476
TOTAL DEPTH (cm)	0.406	0.264	0.325	0.323	0.281	0.275	3.262	11.309	9.284	5.128	1.869	1.209

ANNUAL SUMMARY:
Sum of Mean Daily Flow 43.781 cfs = 1.240 cms
Total Depth 13.360 in = 33.933 cm
Maximum Instantaneous Flow 1.180 cfs = 0.033 cms on May 5 at 17.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 225
WATERSHED AREA: 78 ACRES (31 HECTARES)

WATER YEAR 1981
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.031	0.017	0.019	0.088	0.052	0.052	0.063	0.454	0.357	0.394	0.082	0.050
2	0.024	0.026	0.019	0.085	0.048	0.051	0.051	0.457	0.341	0.370	0.079	0.046
3	0.024	0.023	0.019	0.082	0.048	0.051	0.047	0.473	0.328	0.345	0.075	0.041
4	0.024	0.022	0.020	0.077	0.047	0.051	0.046	0.484	0.329	0.323	0.071	0.039
5	0.024	0.021	0.020	0.075	0.047	0.048	0.047	0.499	0.332	0.299	0.070	0.037
6	0.023	0.033	0.020	0.073	0.046	0.046	0.047	0.497	0.364	0.327	0.067	0.036
7	0.021	0.084	0.020	0.069	0.046	0.046	0.047	0.478	0.337	0.335	0.063	0.034
8	0.021	0.046	0.019	0.065	0.046	0.046	0.046	0.463	0.429	0.275	0.061	0.033
9	0.020	0.039	0.019	0.061	0.045	0.046	0.046	0.444	0.380	0.260	0.058	0.032
10	0.019	0.038	0.019	0.060	0.038	0.046	0.046	0.441	0.387	0.242	0.056	0.032
11	0.020	0.034	0.019	0.060	0.035	0.046	0.046	0.432	0.387	0.226	0.054	0.030
12	0.026	0.031	0.020	0.061	0.036	0.046	0.047	0.401	0.474	0.212	0.053	0.028
13	0.026	0.027	0.020	0.060	0.043	0.046	0.046	0.383	0.462	0.199	0.052	0.028
14	0.024	0.023	0.020	0.059	0.060	0.046	0.049	0.378	0.481	0.188	0.052	0.027
15	0.024	0.022	0.020	0.056	0.050	0.047	0.069	0.374	0.462	0.178	0.051	0.025
16	0.023	0.020	0.020	0.054	0.086	0.048	0.072	0.355	0.565	0.167	0.049	0.025
17	0.022	0.019	0.020	0.053	0.063	0.049	0.078	0.339	0.548	0.159	0.046	0.023
18	0.021	0.019	0.020	0.054	0.057	0.049	0.102	0.335	0.545	0.154	0.046	0.023
19	0.021	0.019	0.021	0.053	0.062	0.049	0.128	0.334	0.614	0.150	0.056	0.038
20	0.020	0.019	0.021	0.053	0.059	0.050	0.125	0.322	0.622	0.142	0.051	0.039
21	0.020	0.019	0.028	0.053	0.057	0.050	0.117	0.465	0.586	0.135	0.046	0.035
22	0.019	0.019	0.079	0.054	0.055	0.053	0.145	0.412	0.581	0.129	0.044	0.032
23	0.019	0.019	0.039	0.108	0.055	0.056	0.216	0.427	0.574	0.123	0.043	0.029
24	0.018	0.019	0.036	0.076	0.055	0.056	0.240	0.434	0.552	0.117	0.042	0.025
25	0.018	0.019	0.127	0.063	0.054	0.075	0.227	0.460	0.533	0.121	0.041	0.039
26	0.018	0.019	0.189	0.059	0.053	0.070	0.241	0.432	0.511	0.116	0.040	0.039
27	0.018	0.019	0.140	0.056	0.052	0.065	0.258	0.418	0.486	0.105	0.038	0.068
28	0.017	0.019	0.101	0.055	0.052	0.066	0.298	0.404	0.465	0.099	0.037	0.046
29	0.017	0.019	0.090	0.053		0.066	0.339	0.390	0.439	0.095	0.036	0.038
30	0.017	0.019	0.104	0.053		0.062	0.401	0.405	0.416	0.092	0.079	0.032
31	0.017		0.092	0.053		0.062		0.400		0.088	0.045	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	0.655	0.770	1.418	1.978	1.445	1.638	3.726	12.988	13.888	6.164	1.680	1.048
TOTAL FLOW (cms days)	0.019	0.022	0.040	0.056	0.041	0.046	0.106	0.368	0.393	0.175	0.048	0.030
TOTAL DEPTH (in)	0.200	0.235	0.433	0.604	0.441	0.500	1.137	3.963	4.238	1.881	0.513	0.320
TOTAL DEPTH (cm)	0.507	0.597	1.099	1.533	1.120	1.269	2.888	10.067	10.764	4.777	1.302	0.813

ANNUAL SUMMARY:
Sum of Mean Daily Flow 47.397 cfs = 1.342 cms
Total Depth 14.463 in = 36.737 cm
Maximum Instantaneous Flow 0.880 cfs = 0.025 cms on June 20 at 2.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 225
WATERSHED AREA: 78 ACRES (31 HECTARES)

WATER YEAR 1982
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.032	0.023	0.025	0.018	0.009	0.018	0.020	0.189	1.067	0.563	0.136	0.038
2	0.029	0.023	0.026	0.018	0.009	0.018	0.019	0.254	1.027	0.439	0.132	0.035
3	0.027	0.022	0.026	0.018	0.008	0.018	0.019	0.233	1.034	0.414	0.118	0.034
4	0.026	0.023	0.022	0.018	0.009	0.017	0.019	0.216	1.009	0.404	0.104	0.034
5	0.026	0.022	0.024	0.017	0.014	0.017	0.019	0.204	0.995	0.392	0.097	0.033
6	0.023	0.021	0.040	0.018	0.010	0.017	0.019	0.229	1.006	0.362	0.092	0.032
7	0.024	0.021	0.029	0.018	0.009	0.016	0.018	0.268	1.005	0.357	0.087	0.030
8	0.024	0.021	0.025	0.017	0.009	0.017	0.018	0.239	0.992	0.354	0.086	0.029
9	0.043	0.021	0.026	0.017	0.009	0.017	0.018	0.234	1.015	0.332	0.084	0.032
10	0.056	0.020	0.028	0.017	0.009	0.018	0.021	0.242	1.043	0.309	0.081	0.074
11	0.046	0.020	0.025	0.018	0.008	0.019	0.049	0.279	1.111	0.293	0.081	0.040
12	0.040	0.030	0.022	0.018	0.008	0.018	0.064	0.297	1.213	0.282	0.078	0.054
13	0.034	0.028	0.021	0.016	0.007	0.019	0.048	0.353	1.309	0.308	0.072	0.039
14	0.031	0.030	0.020	0.015	0.051	0.019	0.047	0.435	1.392	0.280	0.071	0.034
15	0.028	0.025	0.020	0.015	0.027	0.019	0.041	0.449	1.432	0.259	0.069	0.032
16	0.026	0.025	0.019	0.015	0.039	0.020	0.039	0.515	1.433	0.259	0.065	0.031
17	0.025	0.035	0.019	0.015	0.025	0.019	0.038	0.577	1.379	0.243	0.062	0.029
18	0.025	0.028	0.018	0.015	0.023	0.019	0.038	0.617	1.304	0.229	0.059	0.027
19	0.023	0.024	0.041	0.014	0.023	0.019	0.037	0.624	1.201	0.215	0.056	0.026
20	0.022	0.024	0.026	0.013	0.030	0.019	0.036	0.690	1.103	0.201	0.060	0.029
21	0.022	0.030	0.022	0.012	0.033	0.019	0.041	0.763	1.011	0.196	0.061	0.026
22	0.022	0.028	0.019	0.011	0.026	0.019	0.061	0.849	0.909	0.191	0.053	0.026
23	0.022	0.025	0.019	0.011	0.023	0.019	0.087	0.938	0.812	0.183	0.049	0.025
24	0.022	0.023	0.019	0.014	0.022	0.019	0.093	1.032	0.722	0.176	0.047	0.023
25	0.020	0.022	0.018	0.012	0.021	0.020	0.091	1.201	0.668	0.169	0.046	0.023
26	0.041	0.022	0.018	0.011	0.020	0.024	0.101	1.289	0.608	0.161	0.043	0.041
27	0.027	0.023	0.018	0.011	0.018	0.025	0.123	1.298	0.562	0.153	0.041	0.065
28	0.025	0.023	0.019	0.011	0.018	0.024	0.127	1.244	0.568	0.147	0.039	0.063
29	0.024	0.023	0.018	0.010		0.023	0.128	1.178	0.563	0.142	0.039	0.041
30	0.023	0.024	0.018	0.010		0.023	0.146	1.129	0.458	0.140	0.056	0.034
31	0.023		0.018	0.009		0.023		1.062		0.136	0.042	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	0.880	0.727	0.706	0.450	0.516	0.598	1.624	19.123	29.950	8.288	2.206	1.075
TOTAL FLOW (cms days)	0.025	0.021	0.020	0.013	0.015	0.017	0.046	0.542	0.848	0.235	0.062	0.030
TOTAL DEPTH (in)	0.268	0.222	0.216	0.137	0.157	0.182	0.496	5.835	9.139	2.529	0.673	0.328
TOTAL DEPTH (cm)	0.682	0.564	0.547	0.348	0.400	0.463	1.259	14.822	23.214	6.424	1.710	0.833

ANNUAL SUMMARY:

Sum of Mean Daily Flow 66.143 cfs = 1.873 cms

Total Depth 20.183 in = 51.266 cm

Maximum Instantaneous Flow 2.240 cfs = 0.063 cms on July 1 at 8.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 225
WATERSHED AREA: 78 ACRES (31 HECTARES)

WATER YEAR 1983
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.038	0.034	0.016	0.016	0.014	0.022	0.033	0.265	0.745	0.149	0.051	0.047
2	0.036	0.029	0.016	0.016	0.016	0.032	0.032	0.286	0.689	0.151	0.048	0.033
3	0.058	0.027	0.016	0.015	0.016	0.030	0.030	0.306	0.631	0.127	0.046	0.026
4	0.042	0.027	0.027	0.015	0.016	0.034	0.031	0.328	0.576	0.115	0.044	0.024
5	0.041	0.029	0.027	0.039	0.015	0.035	0.032	0.399	0.526	0.105	0.042	0.023
6	0.038	0.031	0.022	0.026	0.014	0.034	0.032	0.386	0.481	0.100	0.040	0.022
7	0.048	0.030	0.020	0.039	0.014	0.034	0.032	0.404	0.438	0.093	0.040	0.020
8	0.046	0.035	0.018	0.030	0.013	0.034	0.032	0.408	0.409	0.089	0.039	0.022
9	0.043	0.027	0.018	0.022	0.013	0.043	0.032	0.400	0.377	0.091	0.046	0.024
10	0.041	0.025	0.018	0.020	0.012	0.052	0.031	0.395	0.359	0.116	0.060	0.037
11	0.041	0.025	0.017	0.019	0.012	0.054	0.031	0.394	0.335	0.087	0.059	0.046
12	0.042	0.024	0.017	0.018	0.012	0.051	0.031	0.392	0.340	0.080	0.047	0.028
13	0.040	0.022	0.017	0.018	0.012	0.053	0.032	0.396	0.296	0.075	0.041	0.025
14	0.037	0.022	0.017	0.017	0.012	0.052	0.034	0.398	0.269	0.123	0.058	0.024
15	0.035	0.025	0.016	0.017	0.012	0.049	0.036	0.396	0.266	0.092	0.048	0.023
16	0.034	0.022	0.017	0.017	0.012	0.046	0.037	0.374	0.239	0.084	0.044	0.022
17	0.034	0.022	0.018	0.017	0.013	0.046	0.044	0.396	0.236	0.076	0.037	0.022
18	0.035	0.022	0.018	0.016	0.033	0.046	0.058	0.446	0.240	0.073	0.033	0.025
19	0.035	0.023	0.017	0.015	0.021	0.046	0.073	0.421	0.211	0.071	0.031	0.031
20	0.034	0.021	0.017	0.014	0.018	0.046	0.087	0.479	0.199	0.086	0.031	0.026
21	0.036	0.021	0.016	0.014	0.018	0.046	0.092	0.504	0.188	0.072	0.033	0.024
22	0.039	0.021	0.016	0.015	0.018	0.045	0.117	0.552	0.171	0.063	0.040	0.022
23	0.034	0.022	0.015	0.015	0.019	0.044	0.163	0.611	0.161	0.062	0.036	0.022
24	0.033	0.022	0.015	0.014	0.020	0.044	0.242	0.675	0.157	0.101	0.033	0.021
25	0.034	0.014	0.015	0.012	0.025	0.043	0.196	0.738	0.148	0.077	0.030	0.020
26	0.044	0.014	0.015	0.012	0.024	0.041	0.193	0.797	0.137	0.068	0.028	0.019
27	0.040	0.016	0.016	0.013	0.022	0.039	0.199	0.835	0.141	0.062	0.027	0.018
28	0.034	0.016	0.016	0.013	0.021	0.036	0.210	0.850	0.136	0.060	0.025	0.017
29	0.035	0.016	0.016	0.014		0.036	0.227	0.857	0.135	0.057	0.024	0.016
30	0.036	0.016	0.015	0.014		0.035	0.261	0.842	0.124	0.053	0.023	0.017
31	0.035		0.016	0.014		0.034		0.800		0.053	0.026	
MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	1.197	0.698	0.539	0.552	0.466	1.279	2.678	15.726	9.360	2.708	1.209	0.745
TOTAL FLOW (cms days)	0.034	0.020	0.015	0.016	0.013	0.036	0.076	0.445	0.265	0.077	0.034	0.021
TOTAL DEPTH (in)	0.365	0.213	0.164	0.168	0.142	0.390	0.817	4.799	2.856	0.826	0.369	0.227
TOTAL DEPTH (cm)	0.928	0.541	0.418	0.427	0.361	0.992	2.076	12.189	7.255	2.099	0.937	0.577

ANNUAL SUMMARY:
Sum of Mean Daily Flow 37.157 cfs = 1.052 cms
Total Depth 11.338 in = 28.800 cm
Maximum Instantaneous Flow 0.860 cfs = 0.024 cms on May 29 at 1.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 225
WATERSHED AREA: 78 ACRES (31 HECTARES)

WATER YEAR 1984
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.016	0.014	0.017	0.010	0.022	0.021	0.033	0.191	1.921	0.443	0.101	0.041
2	0.016	0.017	0.015	0.013	0.027	0.021	0.032	0.218	1.779	0.413	0.091	0.036
3	0.016	0.017	0.013	0.083	0.029	0.020	0.032	0.209	1.659	0.386	0.082	0.033
4	0.016	0.029	0.013	0.049	0.029	0.020	0.034	0.196	1.593	0.363	0.077	0.030
5	0.015	0.023	0.013	0.043	0.028	0.020	0.045	0.188	1.543	0.342	0.073	0.028
6	0.014	0.037	0.012	0.041	0.028	0.020	0.049	0.181	1.554	0.323	0.075	0.047
7	0.014	0.027	0.012	0.032	0.027	0.019	0.042	0.190	1.614	0.303	0.067	0.037
8	0.014	0.022	0.011	0.029	0.027	0.018	0.044	0.210	1.569	0.284	0.063	0.047
9	0.031	0.019	0.011	0.027	0.027	0.018	0.045	0.289	1.524	0.267	0.062	0.038
10	0.025	0.017	0.011	0.024	0.026	0.018	0.044	0.252	1.484	0.253	0.061	0.032
11	0.020	0.025	0.011	0.022	0.026	0.023	0.042	0.284	1.545	0.236	0.059	0.029
12	0.018	0.025	0.011	0.021	0.025	0.025	0.041	0.401	1.500	0.223	0.057	0.026
13	0.017	0.023	0.010	0.021	0.029	0.021	0.043	0.509	1.473	0.213	0.055	0.025
14	0.017	0.020	0.011	0.019	0.034	0.020	0.067	0.638	1.439	0.202	0.053	0.023
15	0.017	0.019	0.010	0.019	0.029	0.021	0.118	0.619	1.415	0.188	0.050	0.022
16	0.016	0.019	0.010	0.018	0.027	0.021	0.172	0.610	1.372	0.177	0.049	0.021
17	0.022	0.019	0.010	0.017	0.026	0.021	0.222	0.626	1.311	0.167	0.084	0.019
18	0.027	0.018	0.010	0.017	0.025	0.020	0.255	0.716	1.224	0.166	0.054	0.018
19	0.020	0.017	0.010	0.017	0.025	0.030	0.236	0.769	1.128	0.157	0.049	0.018
20	0.018	0.017	0.010	0.016	0.024	0.077	0.221	0.924	1.074	0.149	0.046	0.065
21	0.016	0.015	0.011	0.015	0.024	0.055	0.213	0.897	1.039	0.143	0.043	0.041
22	0.026	0.014	0.011	0.014	0.023	0.039	0.235	0.978	0.904	0.136	0.043	0.035
23	0.032	0.014	0.011	0.013	0.023	0.037	0.237	1.138	0.816	0.130	0.042	0.033
24	0.023	0.014	0.011	0.064	0.023	0.037	0.216	1.048	0.765	0.126	0.040	0.032
25	0.020	0.014	0.011	0.044	0.022	0.036	0.211	1.035	0.705	0.119	0.039	0.030
26	0.018	0.013	0.011	0.025	0.022	0.036	0.206	1.175	0.640	0.134	0.038	0.030
27	0.017	0.013	0.011	0.022	0.022	0.035	0.200	1.194	0.590	0.128	0.037	0.029
28	0.015	0.013	0.011	0.021	0.022	0.034	0.197	1.294	0.544	0.142	0.035	0.027
29	0.014	0.013	0.011	0.020	0.022	0.034	0.191	1.530	0.518	0.138	0.031	0.025
30	0.014	0.028	0.011	0.020		0.033	0.183	1.923	0.478	0.116	0.038	0.024
31	0.014		0.011	0.020		0.032		1.970		0.104	0.051	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	0.581	0.573	0.348	0.817	0.743	0.880	3.907	22.403	36.717	6.673	1.741	0.940
TOTAL FLOW (cms days)	0.016	0.016	0.010	0.023	0.021	0.025	0.111	0.634	1.040	0.189	0.049	0.027
TOTAL DEPTH (in)	0.177	0.175	0.106	0.249	0.227	0.268	1.192	6.836	11.204	2.036	0.531	0.287
TOTAL DEPTH (cm)	0.450	0.444	0.270	0.633	0.576	0.682	3.028	17.364	28.459	5.172	1.350	0.728

ANNUAL SUMMARY:
Sum of Mean Daily Flow 76.323 cfs = 2.161 cms
Total Depth 23.290 in = 59.156 cm
Maximum Instantaneous Flow 2.210 cfs = 0.063 cms on May 30 at 13.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 225
WATERSHED AREA: 78 ACRES (31 HECTARES)

WATER YEAR 1985
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.022	0.020	0.007	0.006	0.005	0.002	0.040	0.278	0.445	0.106	0.068	0.013
2	0.019	0.024	0.007	0.006	0.006	0.002	0.037	0.350	0.388	0.100	0.120	0.013
3	0.017	0.022	0.007	0.006	0.007	0.002	0.033	0.377	0.365	0.097	0.053	0.013
4	0.017	0.020	0.008	0.006	0.008	0.002	0.032	0.341	0.387	0.092	0.046	0.014
5	0.017	0.019	0.009	0.006	0.008	0.002	0.031	0.359	0.395	0.089	0.046	0.013
6	0.017	0.022	0.009	0.006	0.007	0.002	0.031	0.392	0.370	0.085	0.041	0.027
7	0.016	0.016	0.009	0.006	0.007	0.002	0.037	0.408	0.360	0.084	0.036	0.041
8	0.016	0.013	0.009	0.006	0.007	0.002	0.049	0.401	0.341	0.080	0.035	0.082
9	0.015	0.012	0.010	0.005	0.006	0.002	0.056	0.398	0.325	0.076	0.033	0.055
10	0.014	0.011	0.011	0.005	0.004	0.002	0.074	0.421	0.312	0.077	0.032	0.055
11	0.012	0.011	0.012	0.005	0.003	0.002	0.092	0.421	0.302	0.069	0.037	0.071
12	0.013	0.012	0.013	0.005	0.002	0.002	0.088	0.398	0.291	0.067	0.047	0.062
13	0.037	0.020	0.014	0.005	0.002	0.002	0.130	0.417	0.278	0.064	0.039	0.041
14	0.030	0.017	0.014	0.005	0.002	0.002	0.166	0.417	0.268	0.061	0.032	0.035
15	0.026	0.012	0.014	0.005	0.002	0.002	0.194	0.445	0.260	0.058	0.028	0.046
16	0.024	0.011	0.015	0.005	0.002	0.002	0.209	0.457	0.246	0.056	0.025	0.044
17	0.021	0.010	0.014	0.005	0.002	0.003	0.204	0.468	0.232	0.054	0.024	0.048
18	0.018	0.010	0.015	0.005	0.002	0.004	0.167	0.481	0.218	0.053	0.023	0.039
19	0.017	0.010	0.014*	0.005	0.002	0.005	0.144	0.490	0.206	0.051	0.022	0.033
20	0.020	0.010	0.013*	0.005	0.002	0.006	0.133	0.494	0.195	0.049	0.023	0.030
21	0.020	0.010	0.011*	0.005	0.002	0.007	0.130	0.495	0.185	0.047	0.041	0.027
22	0.020	0.009	0.009	0.005	0.002	0.009	0.123	0.491	0.173	0.046	0.028	0.025
23	0.020	0.015	0.008	0.004	0.002	0.013	0.102	0.502	0.163	0.044	0.023	0.022
24	0.020	0.009	0.007	0.004	0.002	0.014	0.092	0.516	0.157	0.043	0.021	0.020
25	0.020	0.008	0.007	0.004	0.002	0.018	0.088	0.491	0.150	0.042	0.019	0.018
26	0.022	0.008	0.007	0.004	0.002	0.031	0.088	0.453	0.141	0.040	0.018	0.016
27	0.020	0.007	0.007	0.004	0.002	0.036	0.115	0.423	0.132	0.037	0.017	0.015
28	0.020	0.007	0.006	0.004	0.002	0.037	0.140	0.454	0.126	0.035	0.016	0.013
29	0.020	0.006	0.006	0.004		0.037	0.176	0.470	0.119	0.040	0.015	0.012
30	0.020	0.007	0.006	0.004		0.037	0.199	0.454	0.113	0.046	0.014	0.011
31	0.020		0.006	0.004		0.037		0.395		0.041	0.013	
MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	0.609	0.383	0.301	0.146	0.100	0.323	3.199	13.356	7.641	1.927	1.034	0.956
TOTAL FLOW (cms days)	0.017	0.011	0.009	0.004	0.003	0.009	0.091	0.378	0.216	0.055	0.029	0.027
TOTAL DEPTH (in)	0.186	0.117	0.092	0.044	0.030	0.098	0.976	4.075	2.332	0.588	0.315	0.292
TOTAL DEPTH (cm)	0.472	0.297	0.233	0.113	0.077	0.250	2.480	10.352	5.923	1.494	0.801	0.741

ANNUAL SUMMARY:
Sum of Mean Daily Flow 29.975 cfs = 0.849 cms
Total Depth 9.147 in = 23.233 cm
Maximum Instantaneous Flow 0.810 cfs = 0.023 cms on June 1 at 15.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 226
WATERSHED AREA: 94 ACRES (38 HECTARES)

WATER YEAR 1979
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.031	0.021	0.019	0.019	0.012	0.028	0.058	0.692	0.512	0.134	0.027	0.033
2	0.031	0.021	0.019	0.019	0.012	0.028	0.057	0.787	0.473	0.126	0.026	0.028
3	0.031	0.021	0.019	0.019	0.012	0.028	0.056	0.867	0.434	0.122	0.027	0.026
4	0.031	0.025	0.034	0.019	0.012	0.029	0.057	0.988	0.399	0.116	0.026	0.025
5	0.032	0.021	0.019	0.019	0.012	0.047	0.062	1.253	0.371	0.108	0.024	0.023
6	0.032	0.020	0.019	0.019	0.012	0.102	0.076	1.252	0.367	0.104	0.024	0.022
7	0.031	0.022	0.019	0.019	0.012	0.097	0.091	1.071	0.328	0.102	0.023	0.021
8	0.031	0.106	0.019	0.019	0.012	0.068	0.084	0.896	0.296	0.094	0.024	0.021
9	0.031	0.035	0.019	0.019	0.014	0.062	0.087	0.767	0.271	0.092	0.022	0.023
10	0.029	0.021	0.019	0.019	0.018	0.058	0.086	0.708	0.253	0.089	0.022	0.026
11	0.027	0.021	0.019	0.012	0.022	0.056	0.082	0.703	0.237	0.088	0.020	0.023
12	0.025	0.020	0.019	0.012	0.045	0.054	0.079	0.719	0.223	0.072	0.022	0.022
13	0.026	0.019	0.019	0.012	0.090	0.052	0.077	0.796	0.214	0.054	0.024	0.021
14	0.022	0.019	0.019	0.012	0.047	0.051	0.075	1.001	0.203	0.052	0.026	0.020
15	0.022	0.019	0.019	0.012	0.036	0.049	0.076	1.305	0.193	0.050	0.045	0.020
16	0.022	0.019	0.019	0.012	0.033	0.050	0.092	1.640	0.187	0.047	0.029	0.020
17	0.022	0.019	0.019	0.012	0.033	0.051	0.142	1.658	0.191	0.044	0.024	0.019
18	0.022	0.019	0.019	0.012	0.032	0.051	0.126	1.571	0.207	0.040	0.023	0.018
19	0.022	0.019	0.019	0.012	0.031	0.051	0.119	1.512	0.185	0.039	0.022	0.018
20	0.022	0.019	0.019	0.012	0.031	0.050	0.114	1.473	0.173	0.039	0.021	0.017
21	0.022	0.019	0.019	0.012	0.031	0.049	0.111	1.487	0.278	0.038	0.028	0.015
22	0.021	0.019	0.019	0.012	0.031	0.048	0.131	1.573	0.188	0.047	0.024	0.015
23	0.022	0.019	0.019	0.012	0.031	0.048	0.156	1.640	0.168	0.038	0.068	0.014
24	0.021	0.019	0.019	0.012	0.029	0.048	0.179	1.575	0.159	0.034	0.034	0.014
25	0.022	0.019	0.019	0.012	0.028	0.049	0.202	1.374	0.150	0.034	0.026	0.014
26	0.022	0.019	0.019	0.012	0.028	0.048	0.231	1.203	0.141	0.032	0.024	0.014
27	0.022	0.019	0.019	0.012	0.028	0.055	0.301	1.029	0.137	0.031	0.025	0.014
28	0.022	0.019	0.019	0.012	0.029	0.064	0.400	0.871	0.128	0.036	0.023	0.014
29	0.022	0.019	0.019	0.012		0.062	0.511	0.730	0.124	0.032	0.032	0.014
30	0.022	0.019	0.019	0.012		0.060	0.612	0.630	0.132	0.028	0.065	0.014
31	0.022		0.019	0.012		0.059		0.565		0.028	0.055	
MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	0.782	0.696	0.604	0.442	0.763	1.652	4.530	34.336	7.322	1.990	0.905	0.588
TOTAL FLOW (cms days)	0.022	0.020	0.017	0.013	0.022	0.047	0.128	0.972	0.207	0.056	0.026	0.017
TOTAL DEPTH (in)	0.198	0.176	0.153	0.112	0.193	0.418	1.147	8.694	1.854	0.504	0.229	0.149
TOTAL DEPTH (cm)	0.503	0.448	0.388	0.284	0.491	1.062	2.913	22.083	4.709	1.280	0.582	0.378

ANNUAL SUMMARY:
Sum of Mean Daily Flow 54.610 cfs = 1.547 cms
Total Depth 13.828 in = 35.122 cm
Maximum Instantaneous Flow 1.940 cfs = 0.055 cms on May 23 at 24.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 226
WATERSHED AREA: 94 ACRES (38 HECTARES)

WATER YEAR 1980
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.014	0.020	0.055	0.017	0.017	0.033	0.023	0.731	0.571	0.239	0.090	0.044
2	0.013	0.017	0.056	0.017	0.016	0.031	0.023	0.966	0.572	0.308	0.084	0.075
3	0.013	0.018	0.044	0.017	0.034	0.031	0.023	1.147	0.535	0.327	0.083	0.049
4	0.012	0.020	0.034	0.017	0.022	0.031	0.023	1.071	0.538	0.339	0.078	0.041
5	0.012	0.023	0.025	0.017	0.020	0.031	0.026	1.001	0.494	0.337	0.078	0.039
6	0.012	0.021	0.022	0.016	0.019	0.026	0.027	0.946	0.492	0.327	0.073	0.037
7	0.012	0.016	0.026	0.014	0.018	0.024	0.026	0.801	0.451	0.305	0.070	0.035
8	0.012	0.016	0.025	0.012	0.018	0.025	0.026	0.697	0.419	0.281	0.067	0.032
9	0.012	0.015	0.025	0.012	0.018	0.025	0.034	0.657	0.433	0.330	0.064	0.032
10	0.011	0.015	0.031	0.012	0.018	0.025	0.034	0.555	0.393	0.278	0.062	0.053
11	0.011	0.015	0.022	0.012	0.018	0.026	0.028	0.468	0.472	0.250	0.061	0.065
12	0.012	0.015	0.021	0.030	0.015	0.026	0.025	0.411	0.476	0.237	0.058	0.039
13	0.012	0.013	0.020	0.037	0.014	0.026	0.050	0.380	0.479	0.222	0.055	0.060
14	0.011	0.011	0.020	0.056	0.014	0.024	0.082	0.356	0.530	0.252	0.053	0.048
15	0.032	0.010	0.021	0.034	0.014	0.024	0.091	0.349	0.522	0.215	0.053	0.040
16	0.019	0.011	0.010	0.028	0.014	0.024	0.098	0.314	0.486	0.198	0.052	0.037
17	0.028	0.031	0.049	0.026	0.014	0.024	0.169	0.280	0.468	0.185	0.044	0.035
18	0.043	0.018	0.038	0.025	0.024	0.024	0.239	0.252	0.439	0.177	0.124	0.070
19	0.068	0.017	0.028	0.024	0.028	0.024	0.321	0.228	0.402	0.168	0.059	0.053
20	0.029	0.016	0.026	0.023	0.029	0.023	0.419	0.213	0.370	0.160	0.054	0.149
21	0.026	0.016	0.023	0.022	0.024	0.023	0.454	0.201	0.338	0.151	0.050	0.116
22	0.030	0.016	0.023	0.021	0.021	0.022	0.525	0.209	0.344	0.141	0.046	0.075
23	0.047	0.016	0.020	0.020	0.019	0.022	0.593	0.200	0.297	0.134	0.044	0.065
24	0.035	0.016	0.020	0.020	0.019	0.022	0.677	0.200	0.270	0.127	0.042	0.057
25	0.035	0.016	0.021	0.020	0.019	0.022	0.633	0.271	0.247	0.120	0.040	0.051
26	0.031	0.016	0.021	0.019	0.021	0.022	0.657	0.296	0.276	0.113	0.037	0.047
27	0.029	0.016	0.020	0.019	0.033	0.022	0.748	0.335	0.255	0.109	0.041	0.042
28	0.027	0.019	0.018	0.019	0.051	0.022	0.879	0.381	0.218	0.104	0.040	0.040
29	0.030	0.034	0.017	0.019	0.038	0.023	0.925	0.425	0.201	0.099	0.038	0.039
30	0.025	0.052	0.017	0.019		0.023	0.789	0.524	0.193	0.095	0.037	0.034
31	0.021		0.017	0.019		0.023		0.526		0.093	0.055	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	0.722	0.551	0.812	0.664	0.629	0.775	8.667	15.390	12.181	6.421	1.831	1.599
TOTAL FLOW (cms days)	0.020	0.016	0.023	0.019	0.018	0.022	0.245	0.436	0.345	0.182	0.052	0.045
TOTAL DEPTH (in)	0.183	0.140	0.206	0.168	0.159	0.196	2.195	3.897	3.084	1.626	0.464	0.405
TOTAL DEPTH (cm)	0.464	0.355	0.522	0.427	0.404	0.499	5.574	9.898	7.834	4.130	1.178	1.028

ANNUAL SUMMARY:
Sum of Mean Daily Flow 50.242 cfs = 1.423 cms
Total Depth 12.722 in = 32.313 cm
Maximum Instantaneous Flow 1.690 cfs = 0.048 cms on May 2 at 16.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 226
WATERSHED AREA: 94 ACRES (38 HECTARES)

WATER YEAR 1981
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.041	0.026	0.026	0.202	0.071	0.076	0.143	1.159	0.360	0.384	0.075	0.049
2	0.033	0.036	0.025	0.189	0.064	0.073	0.143	1.080	0.339	0.358	0.073	0.046
3	0.032	0.031	0.026	0.182	0.062	0.071	0.139	0.858	0.322	0.335	0.073	0.041
4	0.032	0.030	0.035	0.166	0.059	0.070	0.140	0.727	0.317	0.310	0.073	0.038
5	0.031	0.025	0.032	0.155	0.055	0.065	0.139	0.646	0.348	0.286	0.074	0.035
6	0.030	0.047	0.031	0.144	0.050	0.062	0.140	0.591	0.378	0.290	0.072	0.033
7	0.027	0.109	0.030	0.133	0.045	0.062	0.140	0.538	0.379	0.310	0.070	0.030
8	0.027	0.065	0.029	0.117	0.041	0.061	0.139	0.485	0.559	0.238	0.068	0.027
9	0.025	0.060	0.030	0.109	0.036	0.061	0.139	0.453	0.624	0.223	0.066	0.026
10	0.024	0.054	0.029	0.101	0.033	0.061	0.140	0.439	0.652	0.209	0.063	0.025
11	0.025	0.046	0.028	0.099	0.033	0.061	0.141	0.439	0.676	0.196	0.063	0.023
12	0.035	0.041	0.027	0.098	0.033	0.062	0.141	0.420	0.764	0.185	0.063	0.022
13	0.036	0.033	0.027	0.088	0.035	0.062	0.141	0.404	0.785	0.174	0.058	0.022
14	0.035	0.029	0.027	0.084	0.045	0.062	0.140	0.407	0.858	0.164	0.056	0.021
15	0.034	0.029	0.027	0.072	0.037	0.062	0.163	0.428	0.845	0.157	0.054	0.020
16	0.032	0.028	0.027	0.067	0.081	0.062	0.179	0.422	0.929	0.147	0.052	0.019
17	0.030	0.026	0.027	0.067	0.084	0.062	0.184	0.397	0.884	0.138	0.054	0.019
18	0.029	0.023	0.027	0.066	0.081	0.063	0.204	0.381	0.873	0.136	0.050	0.018
19	0.028	0.023	0.028	0.065	0.081	0.064	0.309	0.385	0.934	0.131	0.056	0.040
20	0.027	0.023	0.028	0.065	0.082	0.066	0.372	0.373	0.933	0.123	0.053	0.039
21	0.027	0.023	0.041	0.064	0.082	0.067	0.397	0.543	0.887	0.121	0.048	0.036
22	0.026	0.023	0.129	0.065	0.081	0.070	0.475	0.502	0.840	0.117	0.044	0.033
23	0.024	0.023	0.065	0.153	0.081	0.072	0.607	0.505	0.775	0.109	0.041	0.030
24	0.024	0.023	0.057	0.106	0.081	0.075	0.725	0.488	0.697	0.102	0.038	0.025
25	0.025	0.022	0.205	0.088	0.081	0.109	0.757	0.510	0.632	0.111	0.035	0.044
26	0.034	0.021	0.413	0.083	0.081	0.132	0.781	0.462	0.579	0.111	0.033	0.044
27	0.032	0.022	0.391	0.078	0.080	0.131	0.712	0.451	0.534	0.097	0.030	0.091
28	0.028	0.028	0.320	0.079	0.079	0.132	0.731	0.429	0.493	0.087	0.028	0.059
29	0.027	0.025	0.262	0.078		0.129	0.810	0.398	0.454	0.083	0.027	0.045
30	0.026	0.025	0.254	0.077		0.133	0.971	0.426	0.415	0.081	0.078	0.039
31	0.026		0.221	0.075		0.138		0.402		0.079	0.043	
MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	0.907	1.016	2.923	3.216	1.754	2.475	10.341	16.145	19.063	5.593	1.707	1.039
TOTAL FLOW (cms days)	0.026	0.029	0.083	0.091	0.050	0.070	0.293	0.457	0.540	0.158	0.048	0.029
TOTAL DEPTH (in)	0.230	0.257	0.740	0.814	0.444	0.627	2.618	4.088	4.827	1.416	0.432	0.263
TOTAL DEPTH (cm)	0.584	0.653	1.880	2.068	1.128	1.592	6.651	10.383	12.260	3.597	1.098	0.668

ANNUAL SUMMARY:
Sum of Mean Daily Flow 66.179 cfs = 1.874 cms
Total Depth 16.757 in = 42.563 cm
Maximum Instantaneous Flow 1.260 cfs = 0.036 cms on June 20 at 1.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 226
WATERSHED AREA: 94 ACRES (38 HECTARES)

WATER YEAR 1982
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.038	0.028	0.025	0.029	0.021	0.053	0.047	0.313*	1.144	0.334	0.113	0.043
2	0.032	0.028	0.026	0.029	0.022	0.053	0.044	0.400*	1.246	0.320	0.115	0.040
3	0.029	0.025	0.024	0.029	0.022	0.053	0.046	0.477*	1.383	0.337	0.107	0.038
4	0.028	0.023	0.022	0.029	0.022	0.048	0.046	0.603*	1.398	0.334	0.100	0.037
5	0.027	0.021	0.023	0.029	0.021	0.042	0.046	0.610*	1.326	0.325	0.094	0.035
6	0.026	0.020	0.045	0.028	0.021	0.040	0.046	0.656*	1.239	0.305	0.087	0.034
7	0.024	0.020	0.038	0.028	0.021	0.040	0.046	0.722*	1.208	0.302	0.081	0.033
8	0.024	0.020	0.034	0.028	0.021	0.040	0.046	0.674*	1.145	0.312	0.079	0.030
9	0.057	0.020	0.033	0.028	0.021	0.040	0.045	0.667*	1.154	0.285	0.071	0.032
10	0.067	0.018	0.033	0.028	0.021	0.040	0.047	0.680*	1.224	0.277	0.063	0.094
11	0.064	0.018	0.033	0.029	0.021	0.041	0.102	0.743*	1.349	0.254	0.065	0.049
12	0.052	0.034	0.032	0.029	0.021	0.041	0.119	0.771*	1.489	0.240	0.066	0.066
13	0.044	0.032	0.031	0.025	0.021	0.041	0.118	0.803*	1.514	0.302	0.060	0.048
14	0.041	0.035	0.030	0.020	0.088	0.041	0.117	0.910	1.438	0.257	0.059	0.043
15	0.036	0.031	0.028	0.019	0.072	0.042	0.112	1.066	1.291	0.223	0.057	0.041
16	0.032	0.030	0.027	0.018	0.105	0.043	0.104	1.183	1.115	0.225	0.054	0.040
17	0.031	0.045	0.027	0.018	0.078	0.041	0.101	1.262	0.987	0.211	0.052	0.038
18	0.033	0.036	0.025	0.018	0.074	0.040	0.099	1.357	0.847	0.197	0.050	0.036
19	0.029	0.032	0.064	0.018	0.070	0.041	0.096	1.303	0.729	0.186	0.048	0.035
20	0.025	0.032	0.041	0.018	0.070	0.040	0.094*	1.247	0.643	0.170	0.058	0.033
21	0.024	0.039	0.036	0.018	0.072	0.040	0.101*	1.280	0.569	0.159	0.058	0.032
22	0.024	0.035	0.034	0.018	0.072	0.040	0.133*	1.460	0.514	0.156	0.050	0.031
23	0.023	0.030	0.033	0.020	0.072	0.040	0.172*	1.715	0.455	0.151	0.045	0.031
24	0.023	0.027	0.032	0.023	0.070	0.040	0.180*	1.826	0.415	0.144	0.044	0.029
25	0.024	0.027	0.030	0.022	0.066	0.040	0.177*	1.962	0.388	0.140	0.039	0.027
26	0.052	0.027	0.030	0.021	0.063	0.043	0.192*	2.145	0.357	0.132	0.038	0.060
27	0.034	0.026	0.029	0.021	0.060	0.047	0.223*	1.972	0.331	0.123	0.038	0.087
28	0.030	0.026	0.030	0.021	0.056	0.048	0.230*	1.632	0.322	0.117	0.037	0.089
29	0.030	0.026	0.029	0.021		0.047	0.231*	1.362	0.357	0.112	0.036	0.058
30	0.029	0.026	0.029	0.021		0.047	0.255*	1.205	0.251	0.112	0.061	0.049
31	0.028		0.029	0.021		0.048		1.121		0.112	0.046	
MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	1.059	0.837	0.982	0.724	1.361	1.338	3.413	34.126	27.826	6.855	1.972	1.338
TOTAL FLOW (cms days)	0.030	0.024	0.028	0.021	0.039	0.038	0.097	0.966	0.788	0.194	0.056	0.038
TOTAL DEPTH (in)	0.268	0.212	0.249	0.183	0.345	0.339	0.864	8.641	7.046	1.736	0.499	0.339
TOTAL DEPTH (cm)	0.681	0.538	0.631	0.466	0.875	0.861	2.195	21.948	17.896	4.409	1.268	0.860

ANNUAL SUMMARY:
Sum of Mean Daily Flow 81.831 cfs = 2.317 cms
Total Depth 20.720 in = 52.629 cm
Maximum Instantaneous Flow 2.160 cfs = 0.061 cms on May 26 at 8.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 226
WATERSHED AREA: 94 ACRES (38 HECTARES)

WATER YEAR 1983
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.045	0.041	0.017	0.016	0.021	0.037	0.068	0.534	0.420	0.147	0.057	0.070
2	0.041	0.034	0.017	0.015	0.021	0.050	0.067	0.589	0.378	0.151	0.056	0.052
3	0.075	0.032	0.027	0.015	0.020	0.053	0.064	0.647	0.334	0.116	0.051	0.041
4	0.050	0.034	0.041	0.015	0.020	0.054	0.069	0.666	0.303	0.099	0.048	0.036
5	0.048	0.038	0.026	0.051	0.019	0.065	0.069	0.721	0.276	0.089	0.047	0.033
6	0.044	0.041	0.024	0.036	0.018	0.062	0.068	0.786	0.251	0.083	0.046	0.030
7	0.059	0.030	0.023	0.072	0.018	0.063	0.067	0.783	0.231	0.079	0.045	0.028
8	0.055	0.026	0.021	0.053	0.018	0.073	0.067	0.745	0.218	0.078	0.045	0.030
9	0.049	0.027	0.021	0.041	0.018	0.086	0.067	0.663	0.201	0.084	0.054	0.031
10	0.047	0.027	0.020	0.037	0.016	0.099	0.066	0.593	0.207	0.124	0.074	0.053
11	0.047	0.026	0.019	0.035	0.016	0.114	0.066	0.524	0.196	0.087	0.069	0.065
12	0.046	0.022	0.018	0.034	0.016	0.124	0.065	0.473	0.226	0.077	0.054	0.042
13	0.045	0.023	0.019	0.031	0.016	0.136	0.064	0.443	0.182	0.072	0.050	0.036
14	0.043	0.020	0.019	0.028	0.016	0.133	0.063	0.424	0.162	0.135	0.068	0.034
15	0.041	0.020	0.017	0.027	0.016	0.129	0.063	0.429	0.174	0.100	0.056	0.032
16	0.039	0.021	0.021	0.027	0.017	0.124	0.075	0.404	0.149	0.089	0.047	0.030
17	0.039	0.027	0.024	0.026	0.016	0.121	0.099	0.434	0.162	0.081	0.042	0.029
18	0.039	0.028	0.022	0.024	0.045	0.115	0.133	0.543	0.172	0.075	0.041	0.036
19	0.039	0.028	0.022	0.023	0.041	0.107	0.169	0.596	0.148	0.072	0.040	0.048
20	0.038	0.026	0.021	0.023	0.030	0.100	0.207	0.714	0.135	0.093	0.039	0.038
21	0.039	0.024	0.019	0.023	0.028	0.094	0.242	0.788	0.129	0.076	0.039	0.034
22	0.039	0.023	0.019	0.023	0.029	0.088	0.291	0.791	0.119	0.068	0.047	0.032
23	0.036	0.020	0.019	0.023	0.033	0.086	0.404	0.792	0.109	0.066	0.048	0.029
24	0.035	0.019	0.019	0.023	0.033	0.083	0.621	0.795	0.107	0.118	0.044	0.027
25	0.038	0.019	0.019	0.021	0.039	0.080	0.640	0.797	0.098	0.088	0.040	0.026
26	0.051	0.019	0.019	0.020	0.039	0.076	0.581	0.799	0.092	0.078	0.037	0.025
27	0.046	0.018	0.019	0.021	0.038	0.074	0.508	0.802	0.105	0.071	0.034	0.025
28	0.040	0.018	0.018	0.022	0.038	0.072	0.469	0.759	0.096	0.068	0.033	0.023
29	0.047	0.018	0.017	0.022		0.069	0.456	0.644	0.105	0.065	0.031	0.023
30	0.047	0.018	0.018	0.022		0.087	0.489	0.548	0.095	0.062	0.029	0.022
31	0.042		0.017	0.022		0.074		0.477		0.059	0.039	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	1.388	0.768	0.641	0.870	0.694	2.725	6.377	19.701	5.580	2.750	1.447	1.057
TOTAL FLOW (cms days)	0.039	0.022	0.018	0.025	0.020	0.077	0.181	0.558	0.158	0.078	0.041	0.030
TOTAL DEPTH (in)	0.351	0.194	0.162	0.220	0.176	0.690	1.615	4.988	1.413	0.696	0.366	0.268
TOTAL DEPTH (cm)	0.893	0.494	0.412	0.560	0.446	1.753	4.101	12.670	3.589	1.769	0.931	0.680

ANNUAL SUMMARY:
Sum of Mean Daily Flow 43.997 cfs = 1.246 cms
Total Depth 11.140 in = 28.297 cm
Maximum Instantaneous Flow 0.800 cfs = 0.023 cms on May 27 at 2.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 226
WATERSHED AREA: 94 ACRES (38 HECTARES)

WATER YEAR 1984
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.023	0.025	0.028	0.020	0.058	0.036	0.089	0.299	2.248	0.285	0.084*	0.051
2	0.023	0.043	0.028	0.030	0.051	0.042	0.086	0.342	1.816	0.268	0.074*	0.042
3	0.023	0.034	0.027	0.159	0.047	0.036	0.085	0.333	1.604	0.251	0.065*	0.038
4	0.023	0.050	0.027	0.116	0.046	0.035	0.087	0.309	1.585	0.238	0.060*	0.034
5	0.025	0.040	0.027	0.110	0.046	0.033	0.106	0.297	1.646	0.225	0.057*	0.033
6	0.026	0.066	0.026	0.112	0.045	0.032	0.117	0.281	1.738	0.215	0.059*	0.059
7	0.026	0.048	0.026	0.097	0.044	0.030	0.109	0.277	1.867	0.204	0.051*	0.043
8	0.025	0.044	0.026	0.091	0.041	0.030	0.115	0.304	1.825	0.193	0.047*	0.063
9	0.057	0.039	0.026	0.082	0.040	0.031	0.117	0.487	1.667	0.183	0.046*	0.046
10	0.046	0.038	0.026	0.073	0.038	0.034	0.113	0.498	1.483	0.170	0.044*	0.041
11	0.040	0.054	0.027	0.070	0.038	0.045	0.109	0.556	1.547	0.160	0.042*	0.037
12	0.035	0.050	0.027	0.065	0.038	0.043	0.104	0.824	1.499	0.153	0.041*	0.035
13	0.033	0.048	0.026	0.060	0.044	0.041	0.104	1.074	1.405	0.146	0.039*	0.033
14	0.032	0.044	0.026	0.058	0.048	0.049	0.132	1.260*	1.305	0.139	0.038*	0.031
15	0.031	0.042	0.025	0.056	0.042	0.050	0.233	1.234*	1.221	0.132	0.037*	0.030
16	0.030	0.042	0.025	0.052	0.040	0.049	0.389	1.220*	1.110	0.125	0.037*	0.029
17	0.041	0.044	0.025	0.050	0.039	0.049	0.639	1.245*	0.941	0.119	0.073*	0.026
18	0.049	0.043	0.025	0.046	0.038	0.049	0.778	1.373*	0.810	0.127	0.045*	0.026
19	0.040	0.041	0.025	0.044	0.036	0.064	0.755	1.449*	0.715	0.117	0.041*	0.025
20	0.035	0.038	0.025	0.041	0.036	0.139	0.641	1.674*	0.661	0.111	0.040*	0.101
21	0.032	0.035	0.024	0.039	0.035	0.130	0.546	1.636*	0.700	0.107	0.039*	0.059
22	0.050	0.030	0.024	0.038	0.033	0.112	0.520	1.754*	0.578	0.099	0.039*	0.050
23	0.061	0.030	0.024	0.035	0.032	0.110	0.515	1.977*	0.509	0.096	0.041*	0.053
24	0.048	0.030	0.024	0.140	0.032	0.108	0.478	1.853*	0.481	0.094	0.041*	0.050
25	0.042	0.031	0.024	0.124	0.032	0.106	0.442	1.835*	0.461	0.090	0.039*	0.046
26	0.039	0.031	0.024	0.089	0.031	0.100	0.401	1.938*	0.409	0.138	0.037*	0.046
27	0.036	0.030	0.024	0.081	0.031	0.098	0.363	1.961*	0.389	0.132	0.034*	0.045
28	0.032	0.030	0.024	0.075	0.031	0.096	0.334	2.090*	0.351	0.122	0.032*	0.042
29	0.031	0.030	0.023	0.070	0.032	0.093	0.309	2.306*	0.330	0.150	0.033*	0.039
30	0.031	0.029	0.020	0.064		0.091	0.289	3.005	0.308	0.105	0.056	0.037
31	0.030		0.020	0.060		0.090		2.879		0.090	0.065	
MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	1.093	1.179	0.776	2.249	1.144	2.052	9.104	38.568	33.210	4.780	1.475	1.291
TOTAL FLOW (cms days)	0.031	0.033	0.022	0.064	0.032	0.058	0.258	1.092	0.940	0.135	0.042	0.037
TOTAL DEPTH (in)	0.277	0.299	0.196	0.570	0.290	0.520	2.305	9.766	8.409	1.210	0.374	0.327
TOTAL DEPTH (cm)	0.703	0.758	0.499	1.447	0.736	1.320	5.855	24.805	21.359	3.074	0.949	0.830

ANNUAL SUMMARY:

Sum of Mean Daily Flow 96.921 cfs = 2.745 cms
Total Depth 24.541 in = 62.335 cm
Maximum Instantaneous Flow 3.470 cfs = 0.098 cms on May 30 at 13.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 226
WATERSHED AREA: 94 ACRES (38 HECTARES)

WATER YEAR 1985
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.035	0.027	0.021	0.016	0.013	0.011	0.061	0.758	0.483	0.083	0.084	0.020
2	0.032	0.049	0.024	0.016	0.013	0.011	0.089	1.029	0.425	0.075	0.132	0.020
3	0.030	0.048	0.045	0.016	0.012	0.011	0.070	1.118	0.412	0.071	0.057	0.019
4	0.029	0.036	0.058	0.016	0.015	0.011	0.062	1.015	0.447	0.068	0.062	0.019
5	0.029	0.031	0.046	0.016	0.015	0.011	0.065	0.842	0.449	0.065	0.050	0.019
6	0.028	0.047	0.048	0.015	0.013	0.011	0.079	0.754	0.425	0.063	0.040	0.037
7	0.027	0.039	0.028	0.016	0.013	0.011	0.100	0.744	0.436	0.065	0.034	0.056
8	0.026	0.035	0.022	0.015	0.013	0.011	0.146	0.756	0.412	0.063	0.032	0.139
9	0.025	0.031	0.021	0.015	0.012	0.011	0.172	0.737	0.388	0.059	0.031	0.088
10	0.024	0.030	0.020	0.015	0.012	0.011	0.217	0.719	0.362	0.060	0.041	0.100
11	0.038	0.030	0.019	0.015	0.012	0.011	0.289	0.670	0.332	0.054	0.048	0.101
12	0.045	0.033	0.019	0.015	0.012	0.011	0.281	0.600	0.311	0.051	0.054	0.125
13	0.058	0.050	0.019	0.015	0.011	0.011	0.321	0.549	0.279	0.050	0.046	0.067
14	0.044	0.040	0.019	0.015	0.011	0.013	0.416	0.536	0.250	0.049	0.038	0.060
15	0.040	0.033	0.019	0.014	0.011	0.014	0.523	0.543	0.233	0.049	0.033	0.077
16	0.034	0.031	0.019	0.013	0.011	0.016	0.603	0.600	0.213	0.049	0.030	0.063
17	0.028	0.030	0.019	0.013	0.011	0.017	0.613	0.669	0.195	0.048	0.028	0.087
18	0.028	0.029	0.017	0.013	0.010	0.019	0.555	0.700	0.178	0.046	0.026	0.061
19	0.028	0.028	0.032	0.013	0.010	0.020	0.486	0.690	0.167	0.044	0.025	0.056
20	0.026	0.028	0.051	0.013	0.010	0.022	0.407	0.632	0.158	0.042	0.024	0.052
21	0.025	0.028	0.021	0.013	0.010	0.023	0.348	0.563	0.151	0.040	0.056	0.050
22	0.025	0.026	0.017	0.013	0.010	0.023	0.307	0.495	0.142	0.039	0.038	0.046
23	0.024	0.024	0.016	0.014	0.011	0.023	0.261	0.451	0.134	0.037	0.032	0.043
24	0.025	0.025	0.016	0.013	0.011	0.022	0.238	0.447	0.128	0.037	0.028	0.041
25	0.035	0.024	0.016	0.014	0.011	0.022	0.215	0.387	0.125	0.035	0.026	0.038
26	0.044	0.024	0.015	0.013	0.011	0.023	0.202	0.341	0.118	0.034	0.024	0.037
27	0.034	0.026	0.015	0.013	0.011	0.023	0.243	0.312	0.108	0.033	0.022	0.036
28	0.032	0.023	0.016	0.013	0.011	0.023	0.283	0.367	0.102	0.032	0.021	0.035
29	0.030	0.023	0.015	0.013		0.023	0.392	0.394	0.097	0.037	0.021	0.033
30	0.029	0.022	0.015	0.013		0.024	0.527	0.423	0.089	0.049	0.021	0.031
31	0.027		0.015	0.013		0.031		0.392		0.048	0.020	
MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	0.984	0.948	0.740	0.438	0.325	0.522	8.567	19.231	7.745	1.574	1.225	1.656
TOTAL FLOW (cms days)	0.028	0.027	0.021	0.012	0.009	0.015	0.243	0.545	0.219	0.045	0.035	0.047
TOTAL DEPTH (in)	0.249	0.240	0.187	0.111	0.082	0.132	2.169	4.870	1.961	0.399	0.310	0.419
TOTAL DEPTH (cm)	0.633	0.610	0.476	0.281	0.209	0.336	5.510	12.369	4.981	1.013	0.788	1.065

ANNUAL SUMMARY:
Sum of Mean Daily Flow 43.955 cfs = 1.245 cms
Total Depth 11.130 in = 28.269 cm
Maximum Instantaneous Flow 1.160 cfs = 0.033 cms on June 1 at 16.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 227
WATERSHED AREA: 167 ACRES (67 HECTARES)

WATER YEAR 1979
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.166	0.154	0.154	0.154	0.154	0.164	0.235	1.281	0.613	0.408	0.202	0.214
2	0.167	0.154	0.154	0.154	0.154	0.165	0.228	1.368	0.588	0.394	0.201	0.196
3	0.168	0.154	0.154	0.154	0.154	0.165	0.218	1.354	0.564	0.382	0.197	0.187
4	0.172	0.154	0.208	0.154	0.154	0.158	0.213	1.594	0.543	0.372	0.196	0.189
5	0.176	0.154	0.154	0.154	0.154	0.199	0.223	1.954	0.537	0.350	0.192	0.179
6	0.183	0.154	0.154	0.154	0.154	0.372	0.269	1.734	0.575	0.342	0.190	0.173
7	0.194	0.154	0.154	0.154	0.154	0.392	0.332	1.399	0.557	0.345	0.189	0.146
8	0.512	0.154	0.154	0.154	0.154	0.267	0.309	1.178	0.523	0.321	0.188	0.146
9	0.289	0.154	0.154	0.154	0.157	0.245	0.316	1.024	0.496	0.314	0.184	0.152
10	0.180	0.154	0.154	0.154	0.164	0.226	0.308	0.989	0.474	0.310	0.182	0.174
11	0.154	0.154	0.154	0.154	0.173	0.215	0.291	1.038	0.457	0.302	0.178	0.159
12	0.154	0.154	0.154	0.154	0.220	0.211	0.280	1.052	0.447	0.297	0.181	0.150
13	0.154	0.154	0.154	0.154	0.335	0.205	0.270	1.223	0.441	0.288	0.188	0.146
14	0.154	0.154	0.154	0.154	0.238	0.201	0.263	1.373	0.430	0.280	0.200	0.133
15	0.154	0.154	0.154	0.154	0.196	0.197	0.259	1.700	0.419	0.272	0.246	0.134
16	0.154	0.154	0.154	0.154	0.183	0.206	0.296	1.851	0.418	0.265	0.210	0.134
17	0.154	0.154	0.154	0.154	0.176	0.213	0.443	1.672	0.424	0.262	0.196	0.136
18	0.154	0.154	0.154	0.154	0.171	0.211	0.414	1.585	0.488	0.254	0.191	0.138
19	0.154	0.154	0.154	0.154	0.169	0.205	0.378	1.449	0.464	0.249	0.189	0.141
20	0.154	0.154	0.154	0.154	0.167	0.201	0.347	1.356	0.435	0.242	0.183	0.136
21	0.154	0.154	0.154	0.154	0.166	0.199	0.329	1.316	0.856	0.238	0.198	0.132
22	0.154	0.154	0.154	0.154	0.166	0.195	0.393	1.264	0.544	0.269	0.195	0.133
23	0.154	0.154	0.154	0.154	0.165	0.192	0.438	1.207	0.476	0.245	0.305	0.133
24	0.154	0.154	0.154	0.154	0.165	0.191	0.471	1.188	0.446	0.231	0.242	0.135
25	0.154	0.154	0.154	0.154	0.164	0.191	0.508	0.989	0.424	0.227	0.203	0.136
26	0.154	0.154	0.154	0.154	0.165	0.191	0.562	0.891	0.405	0.222	0.194	0.138
27	0.154	0.154	0.154	0.154	0.164	0.212	0.695	0.811	0.402	0.218	0.194	0.138
28	0.154	0.154	0.154	0.154	0.164	0.275	0.902	0.761	0.391	0.233	0.190	0.138
29	0.154	0.154	0.154	0.154		0.282	1.077	0.711	0.381	0.228	0.217	0.137
30	0.154	0.154	0.154	0.154		0.261	1.192	0.670	0.403	0.212	0.330	0.137
31	0.154		0.154	0.154		0.245		0.641		0.206	0.290	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	5.444	4.623	4.830	4.777	4.901	6.853	12.459	38.619	14.621	8.775	6.440	4.517
TOTAL FLOW (cms days)	0.154	0.131	0.137	0.135	0.139	0.194	0.353	1.094	0.414	0.248	0.182	0.128
TOTAL DEPTH (in)	0.776	0.659	0.688	0.681	0.699	0.977	1.776	5.504	2.084	1.251	0.918	0.644
TOTAL DEPTH (cm)	1.971	1.674	1.749	1.729	1.774	2.481	4.510	13.981	5.293	3.177	2.331	1.635

ANNUAL SUMMARY:

Sum of Mean Daily Flow 116.861 cfs = 3.309 cms
Total Depth 16.656 in = 42.305 cm
Maximum Instantaneous Flow 3.800 cfs = 0.108 cms on June 21 at 12.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 227
WATERSHED AREA: 167 ACRES (67 HECTARES)

WATER YEAR 1980
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.128	0.140	0.122	0.125	0.135	0.229	0.154	0.915	0.744	0.491*	0.263	0.208
2	0.112	0.134	0.164	0.125	0.131	0.216	0.154	1.420	0.800	0.778*	0.254	0.292
3	0.112	0.138	0.227	0.125	0.193	0.211	0.153	1.276	0.691	0.801	0.253	0.220
4	0.111	0.153	0.240	0.125	0.167	0.210	0.152	1.027	0.700	0.753	0.248	0.202
5	0.110	0.170	0.186	0.127	0.153	0.205	0.160	0.879	0.625	0.679	0.238	0.189
6	0.110	0.160	0.171	0.127	0.148	0.188	0.163	0.788	0.682	0.617	0.243*	0.184
7	0.110	0.146	0.193	0.124	0.144	0.178	0.155	0.686	0.624	0.570	0.245*	0.183
8	0.109	0.139	0.186	0.122	0.144	0.177	0.154	0.622	0.578	0.515	0.243*	0.179
9	0.109	0.132	0.188	0.121	0.142	0.174	0.175	0.550	0.619	0.627	0.240*	0.176
10	0.111	0.126	0.214	0.119	0.140	0.170	0.170	0.540	0.563	0.531	0.237*	0.230
11	0.112	0.126	0.170	0.118	0.139	0.170	0.166	0.473	0.798	0.478	0.233*	0.274
12	0.113	0.117	0.163	0.188	0.134	0.169	0.171	0.424	0.876	0.449	0.228*	0.200
13	0.113	0.119	0.156	0.241	0.128	0.169	0.231	0.399	0.827	0.427	0.222*	0.253
14	0.113	0.118	0.154	0.311	0.129	0.168	0.333	0.374	0.818	0.524	0.207*	0.230
15	0.184	0.118*	0.155	0.224	0.128	0.168	0.367	0.418	0.801	0.446	0.195	0.201
16	0.148	0.129*	0.153	0.197	0.128	0.165	0.358	0.397	0.709	0.408	0.195	0.188
17	0.178	0.211*	0.254	0.183	0.132	0.165	0.529	0.366	0.659	0.385	0.194	0.178
18	0.219	0.163	0.222	0.173	0.173	0.167	0.687	0.331	0.616	0.374	0.399	0.303
19	0.312	0.145	0.187	0.168	0.203	0.166	0.849	0.290	0.570	0.362	0.233	0.245
20	0.181	0.133	0.175	0.162	0.204	0.164	1.027	0.269	0.533	0.350	0.211	0.540
21	0.172	0.124	0.166	0.160	0.181	0.163	1.091	0.263	0.505	0.340	0.208	0.360
22	0.182	0.124	0.156	0.159	0.168	0.163	1.136	0.320	0.551	0.328	0.202	0.282
23	0.235	0.128	0.147	0.157	0.162	0.163	1.263	0.341	0.488	0.317	0.196	0.250
24	0.191	0.127	0.150	0.152	0.156	0.161	1.417	0.370	0.462	0.308	0.191	0.229
25	0.182	0.127	0.148	0.148	0.155	0.157	1.152	0.709	0.432*	0.299	0.189	0.216
26	0.176	0.126	0.145	0.143	0.170	0.157	1.205	0.880	0.475*	0.291	0.186	0.207
27	0.165	0.126	0.138	0.138	0.235	0.157	1.286	0.916	0.460*	0.284	0.187	0.199
28	0.163	0.125	0.131	0.135	0.303	0.157	1.329	0.848	0.428*	0.279	0.188	0.191
29	0.169	0.123	0.127	0.135	0.259	0.157	1.242	0.761	0.414*	0.271	0.184	0.185
30	0.159	0.123	0.125	0.135		0.155	0.956	0.776	0.413*	0.265	0.179	0.177
31	0.145		0.125	0.135		0.155		0.688		0.265	0.232	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	4.732	4.068	5.235	4.803	4.781	5.374	18.385	19.313	18.457	13.808	6.922	6.970
TOTAL FLOW (cms days)	0.134	0.115	0.148	0.136	0.135	0.152	0.521	0.547	0.523	0.391	0.196	0.197
TOTAL DEPTH (in)	0.674	0.580	0.746	0.684	0.681	0.766	2.620	2.753	2.631	1.968	0.987	0.993
TOTAL DEPTH (cm)	1.713	1.473	1.895	1.739	1.731	1.945	6.655	6.992	6.682	4.999	2.506	2.523

ANNUAL SUMMARY:
Sum of Mean Daily Flow 112.847 cfs = 3.196 cms
Total Depth 16.084 in = 40.852 cm
Maximum Instantaneous Flow 4.140 cfs = 0.117 cms on May 5 at 16.00 hours

* Indicates sc.: data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 227
WATERSHED AREA: 167 ACRES (67 HECTARES)

WATER YEAR 1981
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.172	0.145	0.157	0.420*	0.214	0.216	0.327	0.957	0.530	0.647	0.292	0.248
2	0.168	0.172	0.157	0.394*	0.196	0.211	0.307	0.842	0.501	0.623	0.282	0.232
3	0.167	0.155	0.162	0.378*	0.193	0.206	0.299	0.722	0.481	0.599	0.276	0.212
4	0.165	0.154	0.198	0.355*	0.187	0.201	0.290	0.665	0.511	0.580	0.270	0.200
5	0.162	0.147	0.177	0.335*	0.184	0.198	0.288	0.607	0.494	0.561	0.270	0.194
6	0.158	0.227	0.169	0.316*	0.180	0.199	0.282	0.541	0.794	0.752	0.262	0.189
7	0.150	0.431	0.165	0.299*	0.179	0.200	0.269	0.504	0.678	0.808	0.255	0.183
8	0.150	0.290	0.163	0.278*	0.177	0.199	0.257	0.480	1.207	0.603	0.247	0.178
9	0.150	0.258	0.162	0.259	0.173	0.199	0.255	0.455	1.150	0.557	0.241	0.172
10	0.149	0.248	0.160	0.236	0.143	0.199	0.252	0.462	1.020	0.529	0.236	0.169
11	0.149	0.210	0.157	0.227	0.136	0.198	0.243	0.514	0.971	0.512	0.227	0.165
12	0.173	0.196	0.155	0.224	0.159	0.196	0.236	0.474	1.221	0.500	0.223	0.162
13	0.168	0.166	0.155	0.219	0.191	0.195	0.235	0.438	1.262	0.487	0.222	0.159
14	0.166	0.146	0.154	0.212	0.286	0.196	0.234	0.444	1.241	0.471	0.221	0.157
15	0.163	0.147	0.167	0.198	0.236	0.196	0.305	0.500	1.089	0.456	0.219	0.156
16	0.161	0.144	0.174	0.191	0.369	0.212	0.351	0.459	1.329	0.443	0.216	0.153
17	0.158	0.142	0.178	0.189	0.341	0.212	0.369	0.446	1.263	0.431	0.212	0.151
18	0.158	0.145	0.169	0.189	0.305	0.208	0.469	0.429	1.162	0.430	0.204	0.147
19	0.157	0.147	0.160	0.190	0.349	0.209	0.677	0.431	1.314	0.421	0.250	0.206
20	0.155	0.146	0.156	0.189	0.328	0.211	0.781	0.420	1.322	0.404	0.232	0.179
21	0.153	0.150	0.205	0.196	0.308	0.216	0.723	0.829	1.135	0.396	0.214	0.181
22	0.153	0.169	0.502	0.211	0.293	0.219	0.777	0.736	1.046	0.386	0.205	0.167
23	0.144	0.163	0.292	0.492	0.283	0.222	0.983	0.712	0.977	0.371	0.199	0.161
24	0.144	0.160	0.242	0.366	0.271	0.223	1.155	0.671	0.900	0.360	0.194	0.150
25	0.153	0.158	0.470*	0.282	0.262	0.314	0.981	0.730	0.836	0.389	0.188	0.209
26	0.161	0.158	0.774*	0.245	0.247	0.343	0.896	0.660	0.783	0.372	0.186	0.195
27	0.152	0.160	0.732*	0.244	0.237	0.338	0.859	0.608	0.743	0.345	0.184	0.357
28	0.145	0.181	0.623*	0.237	0.224	0.335	0.920	0.570	0.713	0.328	0.183	0.253
29	0.144	0.168	0.532*	0.229		0.343	0.957	0.537	0.682	0.316	0.181	0.193
30	0.145	0.161	0.511*	0.227		0.339	0.968	0.581	0.665	0.308	0.351	0.176
31	0.145		0.457*	0.222		0.328		0.629		0.299	0.231	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	4.838	5.442	8.634	8.248	6.651	7.283	15.947	18.053	28.021	14.682	7.173	5.652
TOTAL FLOW (cms days)	0.137	0.154	0.245	0.234	0.188	0.206	0.452	0.511	0.794	0.416	0.203	0.160
TOTAL DEPTH (in)	0.689	0.776	1.230	1.176	0.948	1.038	2.273	2.573	3.994	2.092	1.022	0.806
TOTAL DEPTH (cm)	1.751	1.970	3.125	2.986	2.408	2.636	5.773	6.535	10.144	5.315	2.597	2.046

ANNUAL SUMMARY:
Sum of Mean Daily Flow 130.623 cfs = 3.699 cms
Total Depth 18.617 in = 47.287 cm
Maximum Instantaneous Flow 2.150 cfs = 0.061 cms on June 20 at 1.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 227
WATERSHED AREA: 167 ACRES (67 HECTARES)

WATER YEAR 1982
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.168	0.192	0.153*	0.146*	0.157*	0.211*	0.193*	0.779	1.462	1.334	0.450	0.208
2	0.167	0.183	0.175*	0.146*	0.157*	0.212*	0.195*	1.026	1.609	0.993	0.436	0.201
3	0.161	0.172	0.172*	0.146*	0.156*	0.207*	0.198*	1.149	1.652	0.937	0.427	0.199
4	0.156	0.165	0.159*	0.145*	0.157*	0.200*	0.198*	0.995	1.568	0.943	0.417	0.198
5	0.152	0.162	0.161*	0.146*	0.157*	0.200*	0.198*	0.850	1.461	0.946	0.397	0.195
6	0.151	0.159	0.204*	0.148*	0.157*	0.200*	0.198*	0.783	1.428	0.856	0.383	0.191
7	0.184	0.158	0.173*	0.146*	0.157*	0.199*	0.198*	0.905	1.496	0.853	0.370	0.186
8	0.195	0.156*	0.164*	0.146*	0.156*	0.197*	0.199*	0.893	1.392	0.883	0.371	0.184
9	0.308	0.156*	0.170*	0.146*	0.156*	0.225*	0.198*	0.868	1.412	0.829	0.366	0.193
10	0.320	0.154*	0.174*	0.146*	0.156*	0.219*	0.200*	0.857	1.474	0.760	0.352	0.378
11	0.315	0.154*	0.164*	0.146*	0.156*	0.216*	0.253*	0.874	1.529	0.719	0.365	0.239
12	0.269	0.207*	0.155*	0.146*	0.156*	0.212*	0.273*	0.924	1.562	0.689	0.365	0.298
13	0.225	0.171*	0.156*	0.147*	0.155*	0.211*	0.259*	1.066	1.557	0.885	0.348	0.228
14	0.210	0.172*	0.157*	0.134	0.422*	0.211*	0.248*	1.338	1.529	0.831	0.344	0.202
15	0.199	0.162*	0.153*	0.134	0.224*	0.213*	0.243*	1.512	1.390	0.745	0.328	0.196
16	0.192	0.170*	0.152*	0.134	0.291*	0.211*	0.245*	1.572	1.295	0.750	0.314	0.191
17	0.189	0.212*	0.151*	0.134	0.228*	0.209*	0.247*	1.710	1.211	0.710	0.304	0.186
18	0.182	0.177*	0.149*	0.134	0.216*	0.209*	0.250*	1.924	1.150	0.679	0.294	0.182
19	0.173	0.166*	0.314*	0.134	0.226*	0.210*	0.253*	1.707	1.098	0.652	0.287	0.179
20	0.167	0.161*	0.193*	0.134	0.243*	0.207*	0.255*	1.558	1.062	0.629	0.311	0.195
21	0.161	0.187*	0.165*	0.134	0.245*	0.206*	0.256*	1.659	1.041	0.608	0.303	0.182
22	0.159	0.175*	0.160*	0.134	0.230*	0.202*	0.296*	1.919	1.018	0.594	0.277	0.180
23	0.159	0.167*	0.159*	0.167	0.227*	0.203*	0.382*	2.082	0.968	0.570	0.262	0.177
24	0.159	0.162*	0.158*	0.202	0.226*	0.205*	0.470*	2.069	0.921	0.557	0.254	0.178
25	0.159	0.164*	0.158*	0.178	0.222*	0.205*	0.507*	2.285	0.914	0.546	0.244	0.179
26	0.267	0.155*	0.156*	0.167	0.218*	0.207*	0.531*	2.403	0.875	0.522	0.234	0.246
27	0.215	0.157*	0.149*	0.162	0.214*	0.212*	0.599*	2.021	0.844	0.502	0.223	0.347
28	0.196	0.156*	0.147*	0.159	0.211*	0.212*	0.707*	1.737	1.052	0.483	0.216	0.355
29	0.191	0.153*	0.146*	0.157		0.199*	0.682*	1.514	1.095	0.464	0.213	0.259
30	0.189	0.154*	0.146*	0.157		0.196*	0.667	1.396	0.910	0.456	0.277	0.218
31	0.190		0.146*	0.158*		0.194*		1.346		0.446	0.222	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	6.127	5.039	5.139	4.612	5.676	6.418	9.599	43.718	37.972	22.368	9.954	6.549
TOTAL FLOW (cms days)	0.174	0.143	0.146	0.131	0.161	0.182	0.272	1.238	1.075	0.633	0.282	0.185
TOTAL DEPTH (in)	0.873	0.718	0.732	0.657	0.809	0.915	1.368	6.231	5.412	3.188	1.419	0.933
TOTAL DEPTH (cm)	2.218	1.824	1.860	1.670	2.055	2.323	3.475	15.826	13.746	8.098	3.603	2.371

ANNUAL SUMMARY:
Sum of Mean Daily Flow 163.170 cfs = 4.621 cms
Total Depth 23.256 in = 59.070 cm
Maximum Instantaneous Flow 5.800 cfs = 0.164 cms on July 1 at 8.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 227
WATERSHED AREA: 167 ACRES (67 HECTARES)

WATER YEAR 1983
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.204	0.235	0.169	0.144	0.167	0.245	0.253	0.867	0.455	0.465	0.208	0.227
2	0.196	0.217	0.169	0.141	0.156	0.288	0.252	0.932	0.446	0.435	0.202	0.198
3	0.313	0.214	0.194	0.142	0.155	0.285	0.248	0.903	0.421	0.352	0.190	0.163
4	0.248	0.227	0.280	0.149	0.151	0.320	0.264	0.881	0.394	0.312	0.185	0.155
5	0.236	0.240	0.212	0.321	0.146	0.333	0.270	1.099	0.375	0.282	0.177	0.150
6	0.221	0.260	0.203	0.270	0.147	0.325	0.263	1.058	0.360	0.267	0.174	0.145
7	0.281	0.220	0.191	0.422	0.148	0.339	0.261	0.917	0.348	0.260	0.182	0.141
8	0.266	0.211	0.177	0.346	0.147	0.352	0.259	0.857	0.352	0.258	0.180	0.141
9	0.244	0.214	0.172	0.276	0.147	0.408	0.258	0.751	0.343	0.281	0.203	0.139
10	0.231	0.208	0.168	0.249	0.146	0.475	0.255	0.688	0.376	0.379	0.206	0.219
11	0.239	0.201	0.163	0.226	0.151	0.514	0.248	0.628	0.365	0.285	0.255	0.248
12	0.229	0.194	0.163	0.218	0.168	0.509	0.247	0.591	0.466	0.259	0.203	0.172
13	0.214	0.187	0.164	0.209	0.165	0.520	0.241	0.582	0.375	0.246	0.184	0.161
14	0.202	0.179	0.162	0.203	0.163	0.484	0.239	0.584	0.342	0.408	0.224	0.154
15	0.195	0.178	0.158	0.197	0.161	0.444	0.239	0.657	0.374	0.318	0.211	0.148
16	0.190	0.182	0.172	0.191	0.160	0.408	0.252	0.611	0.333	0.286	0.188	0.142
17	0.198	0.200	0.186	0.187	0.164	0.379	0.298	0.709	0.371	0.261	0.171	0.138
18	0.202	0.205	0.172	0.182	0.280	0.354	0.390	0.964	0.397	0.249	0.163	0.169
19	0.193	0.200	0.168	0.179	0.238	0.333	0.500	0.889	0.349	0.243	0.160	0.181
20	0.195	0.195	0.166	0.178	0.209	0.319	0.600	0.939	0.333	0.304	0.159	0.159
21	0.213	0.187	0.165	0.177	0.203	0.315	0.684	0.927	0.327	0.251	0.171	0.155
22	0.218	0.177	0.167	0.175	0.225	0.306	0.739	0.881	0.307	0.230	0.194	0.148
23	0.198	0.169	0.166	0.175	0.240	0.279	0.954	0.848	0.291	0.227	0.177	0.142
24	0.198	0.165	0.162	0.175	0.261	0.270	1.406	0.807	0.287	0.427	0.169	0.137
25	0.213	0.166	0.156	0.169	0.273	0.266	1.116	0.760	0.275	0.300	0.160	0.135
26	0.252	0.165	0.158	0.167	0.269	0.259	0.901	0.710	0.269	0.264	0.154	0.137
27	0.236	0.167	0.157	0.183	0.253	0.253	0.781	0.656	0.312	0.244	0.149	0.137
28	0.219	0.174	0.154	0.183	0.243	0.246	0.741	0.605	0.295	0.233	0.144	0.135
29	0.241	0.175	0.151	0.176		0.248	0.755	0.554	0.321	0.223	0.138	0.133
30	0.245	0.174	0.147	0.173		0.300	0.818	0.508	0.297	0.211	0.135	0.148
31	0.236		0.146	0.170		0.270		0.478		0.207	0.169	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	6.967	5.882	5.336	6.352	5.338	10.645	14.730	23.840	10.552	8.964	5.582	4.756
TOTAL FLOW (cms days)	0.197	0.167	0.151	0.180	0.151	0.301	0.417	0.675	0.299	0.254	0.158	0.135
TOTAL DEPTH (in)	0.993	0.838	0.760	0.905	0.761	1.517	2.099	3.398	1.504	1.278	0.796	0.678
TOTAL DEPTH (cm)	2.522	2.129	1.932	2.300	1.932	3.854	5.333	8.630	3.820	3.245	2.021	1.722

ANNUAL SUMMARY:
Sum of Mean Daily Flow 108.945 cfs = 3.085 cms
Total Depth 15.527 in = 39.439 cm
Maximum Instantaneous Flow 1.870 cfs = 0.053 cms on July 24 at 14.00 hours

*** Indicates some data were estimated during this day.**

HORSE CREEK STUDY AREA
WATERSHED: 227
WATERSHED AREA: 167 ACRES (67 HECTARES)

WATER YEAR 1984
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.133	0.151	0.156	0.105	0.190	0.166	0.284	0.550	2.340	0.837	0.361	0.195
2	0.132	0.190	0.154	0.135	0.182	0.168	0.278	0.619	2.097	0.803	0.345	0.193
3	0.131	0.172	0.154	0.446	0.178	0.164	0.273	0.572	2.041	0.771	0.332	0.191
4	0.131	0.233	0.150	0.524	0.176	0.163	0.275	0.524	2.202	0.743	0.320	0.190
5	0.133	0.187	0.146	0.410	0.173	0.162	0.318	0.497	2.254	0.719	0.318	0.188
6	0.131	0.292	0.147	0.401	0.169	0.161	0.326	0.478	2.326	0.696	0.352	0.184
7	0.131	0.220	0.150	0.324	0.168	0.160	0.306	0.468	2.590	0.667	0.380	0.184
8	0.131	0.192	0.153	0.297	0.166	0.162	0.329	0.542	2.370	0.642	0.362	0.184
9	0.131	0.180	0.152	0.257	0.167	0.179	0.326	0.945	2.213	0.622	0.275	0.184
10	0.130	0.185	0.151	0.236	0.163	0.193	0.313	0.843	2.097	0.599	0.270	0.183
11	0.131	0.231	0.173	0.222	0.163	0.210	0.311	0.947	2.234	0.582	0.263	0.184
12	0.131	0.224	0.164	0.213	0.163	0.197	0.305	1.348	2.035	0.557	0.260	0.181
13	0.131	0.214	0.160	0.201	0.203	0.206	0.300	1.689	1.910	0.538	0.255	0.180
14	0.130	0.194	0.160	0.191	0.188	0.258	0.351	2.306	1.783	0.518	0.247	0.179
15	0.130	0.195	0.138	0.180	0.180	0.260	0.574	2.050	1.709	0.501	0.237	0.179
16	0.129	0.206	0.139	0.175	0.177	0.262	0.879	1.638	1.587	0.485	0.234	0.179
17	0.132	0.219	0.138	0.171	0.173	0.263	1.242	1.405	1.468	0.469	0.381	0.179
18	0.132	0.202	0.137	0.163	0.171	0.253	1.338	1.501	1.386	0.479	0.259	0.179
19	0.132	0.188	0.134	0.155	0.167	0.293	1.229	1.750	1.320	0.457	0.233	0.179
20	0.132	0.183	0.131	0.145	0.164	0.503	0.993	2.206	1.371	0.436	0.222	0.267
21	0.132	0.174	0.125	0.144	0.165	0.491	0.874	1.929	1.516	0.421	0.217	0.222
22	0.132	0.163	0.118	0.139	0.162	0.412	0.887	1.775	1.258	0.403	0.215	0.208
23	0.132	0.161	0.110	0.138	0.160	0.381	0.871	2.369	1.186	0.395	0.213	0.204
24	0.132	0.181	0.107	0.460	0.159	0.371	0.791	2.001	1.150	0.388	0.209	0.201
25	0.132	0.179	0.105	0.405	0.159	0.353	0.711	1.747	1.155	0.380	0.209	0.196
26	0.133	0.174	0.105	0.266	0.159	0.335	0.664	2.008	1.039	0.644	0.208	0.195
27	0.132	0.170	0.107	0.237	0.159	0.319	0.626	2.047	0.989	0.422	0.211	0.189
28	0.133	0.170	0.104	0.225	0.159	0.311	0.587	2.204	0.937	0.460	0.206	0.187
29	0.134	7.295	0.101	0.214	0.159	0.302	0.548	2.820	0.911	0.475	0.205	0.182
30	0.134	0.157	0.102	0.205		0.294	0.522	3.741	0.880	0.402	0.202	0.178
31	0.134		0.106	0.198		0.291		2.954		0.368	0.197	

MONTHLY SUMMARY:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	4.084	12.882	4.178	7.580	4.921	8.238	17.630	48.469	50.353	16.882	8.196	5.722
TOTAL FLOW (cms days)	0.116	0.365	0.118	0.215	0.139	0.233	0.499	1.373	1.426	0.478	0.232	0.162
TOTAL DEPTH (in)	0.582	1.836	0.596	1.080	0.701	1.174	2.513	6.908	7.177	2.406	1.168	0.815
TOTAL DEPTH (cm)	1.479	4.663	1.513	2.744	1.781	2.982	6.382	17.547	18.229	6.111	2.967	2.071

ANNUAL SUMMARY:

Sum of Mean Daily Flow 189.136 cfs = 5.356 cms
Totml Depth 26.957 in = 68.470 cm
Maximum Instmntaneous Flow 4.920 cfs = 0.139 cms on May 30 at 12.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED 227
WATERSHED AREA: 167 ACRES (67 HECTARES)

WATER YEAR 1985
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.162	0.210	0.134	0.132	0.132*	0.147	0.153	1.055	0.728	0.214	0.310	0.107
2	0.139	0.224	0.133	0.132	0.133*	0.147	0.176	1.293	0.633	0.209	0.409	0.127
3	0.130	0.216	0.132	0.132	0.133*	0.147	0.192	1.204	0.557	0.206	0.193	0.122
4	0.130	0.211	0.132	0.132	0.134*	0.147	0.171	0.960	0.638	0.200	0.208	0.112
5	0.138	0.205	0.131	0.132	0.133*	0.147	0.160	0.793	0.706	0.196	0.172	0.111
6	0.135	0.233	0.129	0.131	0.139*	0.147	0.162	0.772	0.655	0.192	0.152	0.200
7	0.133	0.229	0.128	0.131	0.149	0.147	0.193	0.806	0.633	0.202	0.157	0.198
8	0.131	0.215	0.128	0.131	0.148	0.147	0.302	0.765	0.571	0.198	0.154	0.405
9	0.129	0.196	0.126	0.131	0.148	0.147	0.363	0.706	0.520	0.188	0.144	0.312
10	0.128	0.185	0.128	0.131	0.149	0.147	0.437	0.714	0.484	0.194	0.172	0.318
11	0.160	0.175	0.128	0.131	0.150	0.146	0.588	0.660	0.449	0.182	0.184	0.345
12	0.160	0.194	0.127	0.130	0.150	0.147	0.490	0.555	0.420	0.181	0.206	0.409
13	0.212	0.266	0.122	0.130	0.150	0.146	0.557	0.532	0.394	0.175	0.170	0.212
14	0.165	0.225	0.120	0.130	0.149	0.148	0.725	0.592	0.368	0.170	0.151	0.178
15	0.156	0.176	0.119	0.130	0.149	0.147	0.897	0.605	0.352	0.167	0.142	0.235
16	0.146	0.178	0.119	0.130	0.148	0.147	0.921	0.629	0.329	0.164	0.137	0.192
17	0.144	0.169	0.119	0.130	0.147	0.147	0.852	0.616	0.313	0.161	0.134	0.280
18	0.143	0.162	0.118	0.130	0.147	0.147	0.715	0.584	0.300	0.159	0.134	0.203
19	0.143	0.160	0.121	0.131	0.147	0.147	0.585	0.543	0.288	0.156	0.139	0.183
20	0.143	0.160	0.130	0.131	0.148	0.145	0.481	0.506	0.283	0.152	0.145	0.171
21	0.142	0.160	0.131	0.130	0.148	0.146	0.417	0.466	0.276	0.149	0.187	0.162
22	0.144	0.157	0.131	0.130	0.147	0.147	0.364	0.429	0.269	0.149	0.142	0.154
23	0.151	0.150	0.131	0.130	0.148	0.146	0.317	0.427	0.262	0.147	0.132	0.149
24	0.155	0.150	0.131	0.132	0.147	0.147	0.288	0.505	0.255	0.145	0.125	0.143
25	0.168	0.149	0.131	0.132	0.148	0.147	0.265	0.443	0.254	0.142	0.120	0.139
26	0.211	0.141	0.131	0.133	0.147	0.146	0.250	0.392	0.247	0.139	0.118	0.137
27	0.178	0.144	0.131	0.134	0.147	0.146	0.349	0.369	0.238	0.136	0.114	0.133
28	0.177	0.145	0.130	0.134	0.147	0.146	0.478	0.511	0.231	0.136	0.110	0.129
29	0.176	0.143	0.130	0.134		0.146	0.676	0.656	0.227	0.146	0.108	0.128
30	0.177	0.142	0.132	0.133		0.146	0.778	0.750	0.219	0.155	0.106	0.130
31	0.176		0.132	0.132*		0.146		0.594		0.166	0.107	
MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	4.781	5.467	3.964	4.073	4.064	4.546	13.301	20.429	12.099	5.275	4.981	5.821
TOTAL FLOW (cms days)	0.135	0.155	0.112	0.115	0.115	0.129	0.377	0.579	0.343	0.149	0.141	0.165
TOTAL DEPTH (in)	0.681	0.779	0.565	0.581	0.579	0.648	1.896	2.912	1.724	0.752	0.710	0.830
TOTAL DEPTH (cm)	1.731	1.979	1.435	1.474	1.471	1.646	4.815	7.396	4.380	1.909	1.803	2.107

ANNUAL SUMMARY:
Sum of Mean Daily Flow 88.799 cfs = 2.515 cms
Total Depth 12.656 in = 32.147 cm
Maximum Instantaneous Flow 1.890 cfs = 0.054 cms on August 1 at 22.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 230
WATERSHED AREA: 91 ACRES (36 HECTARES)

WATER YEAR 1979
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.102	0.097	0.088	0.088	0.088	0.077	0.101	0.531	0.373	0.225	0.118	0.109
2	0.103	0.101	0.088	0.088	0.088	0.076	0.099	0.570	0.366	0.216	0.118	0.103
3	0.102	0.099	0.088	0.088	0.088	0.076	0.099	0.593	0.358	0.214	0.116	0.099
4	0.104	0.103	0.118	0.088	0.088	0.076	0.097	0.655	0.348	0.212	0.116	0.099
5	0.104	0.093	0.088	0.088	0.088	0.087	0.105	0.770	0.343	0.205	0.115	0.096
6	0.104	0.092	0.088	0.088	0.088	0.132	0.120	0.777	0.354	0.203	0.114	0.094
7	0.103	0.094	0.088	0.088	0.088	0.135	0.132	0.667	0.340	0.203	0.113	0.092
8	0.102	0.200	0.088	0.088	0.080	0.107	0.121	0.577	0.325	0.196	0.113	0.091
9	0.103	0.107	0.088	0.088	0.072	0.102	0.127	0.501	0.312	0.196	0.111	0.092
10	0.104	0.092	0.088	0.088	0.079	0.099	0.121	0.472	0.303	0.194	0.109	0.100
11	0.103	0.088	0.088	0.088	0.077	0.096	0.118	0.466	0.294	0.194	0.108	0.087
12	0.102	0.088	0.088	0.088	0.111	0.095	0.118	0.470	0.285	0.173	0.107	0.083
13	0.102	0.088	0.088	0.088	0.162	0.095	0.116	0.517	0.279	0.151	0.110	0.085
14	0.102	0.088	0.088	0.088	0.099	0.092	0.117	0.567	0.271	0.147	0.112	0.086
15	0.102	0.088	0.088	0.088	0.086	0.091	0.121	0.660	0.266	0.145	0.130	0.086
16	0.102	0.088	0.088	0.088	0.082	0.093	0.142	0.749	0.261	0.142	0.113	0.084
17	0.102	0.088	0.088	0.088	0.079	0.095	0.175	0.731	0.266	0.138	0.111	0.084
18	0.101	0.088	0.088	0.088	0.079	0.095	0.148	0.690	0.277	0.136	0.106	0.083
19	0.101	0.088	0.088	0.088	0.080	0.094	0.144	0.648	0.259	0.134	0.106	0.080
20	0.099	0.088	0.088	0.088	0.078	0.094	0.143	0.614	0.248	0.134	0.106	0.079
21	0.101	0.088	0.088	0.088	0.078	0.093	0.144	0.575	0.390	0.134	0.115	0.080
22	0.098	0.088	0.088	0.088	0.077	0.092	0.174	0.557	0.266	0.144	0.107	0.080
23	0.098	0.088	0.088	0.088	0.077	0.092	0.180	0.542	0.246	0.136	0.152	0.079
24	0.099	0.088	0.088	0.088	0.077	0.092	0.191	0.548	0.234	0.128	0.118	0.078
25	0.098	0.088	0.088	0.088	0.077	0.092	0.204	0.494	0.226	0.126	0.107	0.078
26	0.098	0.088	0.088	0.088	0.077	0.092	0.227	0.474	0.221	0.125	0.107	0.078
27	0.098	0.088	0.088	0.088	0.077	0.099	0.274	0.450	0.221	0.124	0.106	0.078
28	0.097	0.088	0.088	0.088	0.077	0.120	0.336	0.418	0.215	0.129	0.103	0.078
29	0.100	0.088	0.088	0.088		0.115	0.417	0.397	0.213	0.126	0.128	0.077
30	0.099	0.088	0.088	0.088		0.107	0.486	0.388	0.223	0.121	0.161	0.078
31	0.093		0.088	0.088		0.105		0.381		0.118	0.140	
MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	3.126	2.838	2.760	2.729	2.395	3.004	5.093	17.449	8.583	4.970	3.595	2.596
TOTAL FLOW (cms days)	0.089	0.080	0.078	0.077	0.068	0.085	0.144	0.494	0.243	0.141	0.102	0.074
TOTAL DEPTH (in)	0.818	0.742	0.722	0.714	0.626	0.786	1.332	4.564	2.245	1.300	0.940	0.679
TOTAL DEPTH (cm)	2.077	1.885	1.833	1.813	1.591	1.995	3.384	11.592	5.702	3.302	2.388	1.725

ANNUAL SUMMARY:
Sum of Mean Daily Flow 59.136 cfs = 1.675 cms
Total Depth 15.467 in = 39.287 cm
Maximum Instantaneous Flow 1.830 cfs = 0.052 cms on June 21 at 14.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 230
WATERSHED AREA: 91 ACRES (36 HECTARES)

WATER YEAR 1980
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.079	0.074	0.065	0.081	0.072	0.092	0.080	0.446	0.366	0.376	0.174	0.133
2	0.075	0.077	0.084	0.080	0.072	0.090	0.079	0.583	0.371	0.371	0.171	0.168
3	0.072	0.077	0.092	0.080	0.092	0.092	0.079	0.672	0.331	0.376	0.169	0.137
4	0.071	0.080	0.101	0.079	0.077	0.096	0.081	0.580	0.352	0.376	0.167	0.131
5	0.071	0.084	0.079	0.079	0.074	0.092	0.087	0.526	0.348	0.374	0.165	0.127
6	0.070	0.079	0.074	0.079	0.072	0.087	0.087	0.448	0.349	0.374	0.162	0.124
7	0.070	0.074	0.080	0.077	0.070	0.084	0.083	0.396	0.348	0.333	0.160	0.125
8	0.070	0.072	0.079	0.075	0.070	0.085	0.082	0.356	0.344	0.270	0.159	0.123
9	0.070	0.071	0.080	0.074	0.070	0.084	0.094	0.345	0.336	0.315	0.157	0.122
10	0.070	0.068	0.089	0.072	0.071	0.085	0.089	0.318	0.337	0.268	0.156	0.141
11	0.070	0.067	0.072	0.071	0.071	0.085	0.092	0.289	0.405	0.255	0.154	0.153
12	0.070	0.062	0.072	0.096	0.069	0.084	0.093	0.270	0.439	0.250	0.152	0.127
13	0.071	0.064	0.072	0.107	0.070	0.083	0.117	0.252	0.403	0.243	0.149	0.150
14	0.071	0.060	0.072	0.119	0.070	0.084	0.144	0.242	0.388	0.278	0.147	0.137
15	0.097	0.061	0.073	0.096	0.069	0.083	0.145	0.264	0.451	0.246	0.146	0.126
16	0.081	0.066	0.071	0.088	0.069	0.082	0.142	0.247	0.407	0.234	0.145	0.123
17	0.095	0.091	0.102	0.088	0.070	0.082	0.190	0.222	0.398	0.225	0.141	0.120
18	0.107	0.073*	0.086	0.086	0.087	0.083	0.230	0.213	0.393	0.220	0.212	0.164
19	0.136	0.068*	0.075	0.084	0.094	0.083	0.289	0.209	0.387	0.216	0.153	0.140
20	0.092	0.064*	0.073	0.083	0.092	0.083	0.365	0.206	0.385	0.211	0.147	0.230
21	0.091	0.063	0.069	0.082	0.081	0.083	0.396	0.202	0.385	0.205	0.143	0.186
22	0.098	0.064*	0.067	0.080	0.077	0.082	0.449	0.212	0.385	0.199	0.140	0.148
23	0.106	0.066*	0.062	0.080	0.076	0.082	0.503	0.232	0.385	0.194	0.137	0.139
24	0.093	0.069*	0.064	0.079	0.074	0.082	0.536	0.231	0.384	0.192	0.135	0.133
25	0.097	0.069	0.064	0.077	0.074	0.082	0.517	0.324	0.383	0.189	0.134	0.129
26	0.089	0.067	0.064	0.075	0.082	0.081	0.507	0.336	0.382	0.187	0.132	0.126
27	0.086	0.065	0.066	0.074	0.102	0.081	0.528	0.342	0.381	0.184	0.132	0.123
28	0.085	0.064	0.069	0.074	0.118	0.081	0.559	0.360	0.380	0.182	0.130	0.118
29	0.086	0.064	0.073	0.074	0.101	0.082	0.541	0.364	0.380	0.180	0.127	0.113
30	0.082	0.064	0.076	0.073		0.081	0.470	0.394	0.378	0.177	0.125	0.111
31	0.076		0.079	0.073		0.081		0.376		0.176	0.141	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	2.597	2.085	2.341	2.533	2.284	2.613	7.655	10.455	11.359	7.874	4.660	4.127
TOTAL FLOW (cms days)	0.074	0.059	0.066	0.072	0.065	0.074	0.217	0.296	0.322	0.223	0.132	0.117
TOTAL DEPTH (in)	0.679	0.545	0.612	0.663	0.597	0.683	2.002	2.735	2.971	2.059	1.219	1.079
TOTAL DEPTH (cm)	1.725	1.385	1.555	1.683	1.517	1.736	5.085	6.946	7.546	5.231	3.096	2.742

ANNUAL SUMMARY:
Sum of Mean Daily Flow 60.582 cfs = 1.716 cms
Total Depth 15.846 in = 40.248 cm
Maximum Instantaneous Flow 0.830 cfs = 0.024 cms on April 23 at 23.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 230
WATERSHED AREA: 91 ACRES (36 HECTARES)

WATER YEAR 1981
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.119	0.098	0.096	0.243	0.122	0.131*	0.164	0.391	0.247	0.375	0.191	0.149
2	0.118	0.111	0.104	0.229	0.115	0.131*	0.157	0.361	0.242	0.365	0.188	0.141
3	0.117	0.102	0.112	0.220	0.115	0.132*	0.153	0.320	0.242	0.354	0.184	0.134
4	0.115	0.101	0.114	0.209	0.113	0.131*	0.151	0.293	0.249	0.342	0.181	0.131
5	0.114	0.099	0.100	0.199	0.114	0.129*	0.154	0.273	0.306	0.354	0.177	0.128
6	0.112	0.137	0.097	0.188	0.113	0.125	0.150	0.249	0.286	0.415	0.176	0.126
7	0.110	0.187	0.095	0.180	0.113	0.123	0.146	0.235	0.288	0.358	0.176	0.123
8	0.110	0.143	0.092	0.167	0.114	0.123	0.143	0.225	0.418	0.327	0.173	0.121
9	0.109	0.139	0.090	0.158	0.113	0.122	0.141	0.220	0.403	0.314	0.170	0.122
10	0.108	0.127	0.089	0.150	0.101	0.122	0.138	0.221	0.448	0.307	0.167	0.123
11	0.108	0.119	0.089	0.143	0.100	0.120	0.139	0.235	0.446	0.298	0.159	0.121
12	0.120	0.112	0.091	0.140	0.120	0.120	0.135	0.218	0.507	0.290	0.157	0.117
13	0.118	0.098	0.090	0.136	0.129	0.121	0.133	0.212	0.478	0.284	0.156	0.116
14	0.117	0.092	0.090	0.132	0.161	0.121	0.142	0.235	0.524	0.276	0.155	0.115
15	0.116	0.093	0.100	0.125	0.126	0.122	0.165	0.233	0.489	0.269	0.153	0.113
16	0.114	0.088	0.101	0.120	0.200	0.128	0.165	0.222	0.597	0.262	0.150	0.111
17	0.112	0.092	0.101	0.121	0.149	0.123	0.169	0.213	0.514	0.257	0.146	0.109
18	0.110	0.095	0.095	0.122	0.143	0.120	0.200	0.211	0.572	0.257	0.146	0.109
19	0.109	0.096	0.093	0.121	0.161	0.123	0.240	0.205	0.594	0.253	0.158	0.132
20	0.108	0.096	0.093	0.120	0.148	0.129	0.254	0.277	0.547	0.243	0.147	0.119
21	0.106	0.099	0.117	0.121	0.144	0.124	0.268	0.263	0.556	0.238	0.142	0.120
22	0.105	0.102	0.222	0.122	0.143	0.128	0.314	0.260	0.535	0.232	0.141	0.114
23	0.102	0.093	0.136	0.197	0.144	0.128	0.360	0.279	0.502	0.224	0.139	0.112
24	0.101	0.091	0.130	0.153	0.144	0.126	0.414	0.294	0.474	0.219	0.136	0.109
25	0.101	0.089	0.289	0.131	0.144*	0.167	0.416	0.290	0.456	0.229	0.135	0.131
26	0.114	0.089	0.423	0.125	0.132*	0.157	0.398	0.283	0.443	0.220	0.134	0.119
27	0.106	0.099	0.398	0.125	0.131*	0.156	0.375	0.275	0.429	0.211	0.133	0.172
28	0.101	0.101	0.351	0.126	0.132*	0.161	0.375	0.268	0.422	0.206	0.132	0.135
29	0.101	0.098	0.312	0.124		0.166	0.378	0.262	0.406	0.202	0.131	0.119
30	0.099	0.098	0.306	0.123		0.161	0.389	0.299	0.398	0.199	0.196	0.114
31	0.098		0.262	0.123		0.169		0.257		0.195	0.143	

MONTHLY SUMMARY:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	3.396	3.184	4.876	4.691	3.683	4.138	6.927	8.079	13.020	8.573	4.871	3.702
TOTAL FLOW (cms days)	0.096	0.090	0.138	0.133	0.104	0.117	0.196	0.229	0.369	0.243	0.138	0.105
TOTAL DEPTH (in)	0.888	0.833	1.275	1.227	0.963	1.082	1.812	2.113	3.405	2.242	1.274	0.968
TOTAL DEPTH (cm)	2.256	2.115	3.240	3.117	2.447	2.749	4.602	5.368	8.650	5.696	3.236	2.459

ANNUAL SUMMARY:
Sum of Mean Daily Flow 69.139 cfs = 1.958 cms
Total Depth 18.084 in = 45.933 cm
Maximum Instantaneous Flow 0.900 cfs = 0.025 cms on June 16 at 10.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 230
WATERSHED AREA: 91 ACRES (36 HECTARES)

WATER YEAR 1982
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.124	0.099	0.084	0.079	0.081	0.123	0.107	0.353	0.850	0.496	0.211	0.134
2	0.125	0.097	0.102	0.079	0.081	0.123	0.100	0.426	0.890	0.429	0.208	0.133
3	0.121	0.091	0.095	0.079	0.081	0.119	0.102	0.465	0.935	0.404	0.201	0.133
4	0.119	0.087	0.083	0.079	0.081	0.113	0.102	0.466	0.909	0.398	0.190	0.133
5	0.118	0.086	0.090	0.079	0.081	0.112	0.103	0.421	0.865	0.393	0.189	0.133
6	0.111	0.085	0.127	0.079	0.081	0.111	0.102	0.396	0.838	0.368	0.185	0.133
7	0.111	0.085	0.101	0.075	0.081	0.110	0.102	0.412	0.838	0.367	0.180	0.132
8	0.109	0.085	0.094	0.075	0.081	0.109	0.102	0.391	0.799	0.364	0.181	0.131
9	0.143	0.084	0.098	0.076	0.080	0.131	0.101	0.404	0.787	0.354	0.180	0.156
10	0.145	0.084	0.102	0.076	0.081	0.126	0.102	0.407	0.784	0.335	0.174	0.179
11	0.144	0.084	0.093	0.077	0.081	0.123	0.143	0.416	0.781	0.324	0.173	0.143
12	0.125	0.115	0.086	0.079	0.081	0.121	0.158	0.425	0.771	0.317	0.172	0.161
13	0.115	0.099	0.085	0.080	0.080	0.117	0.144	0.475	0.757	0.365	0.167	0.136
14	0.111	0.100	0.086	0.076	0.182	0.119	0.140	0.573	0.734	0.311	0.166	0.133
15	0.107	0.090	0.085	0.076	0.127	0.120	0.135	0.650	0.707	0.294	0.165	0.131
16	0.105	0.096	0.084	0.076	0.162	0.119	0.136	0.713	0.687	0.295	0.161	0.128
17	0.103	0.122	0.083	0.077	0.137	0.119	0.137	0.752	0.665	0.282	0.158	0.125
18	0.102	0.100	0.082	0.077	0.127	0.119	0.139	0.806	0.654	0.272	0.155	0.122
19	0.099	0.091	0.141	0.076	0.136	0.119	0.140	0.794	0.641	0.264	0.151	0.120
20	0.097	0.092	0.103	0.074	0.149	0.117	0.142	0.753	0.625	0.256	0.166	0.124
21	0.095	0.112	0.095	0.075	0.150	0.116	0.143	0.752	0.606	0.250	0.160	0.117
22	0.094	0.103	0.091	0.075	0.139	0.114	0.155	0.810	0.588	0.243	0.151	0.116
23	0.093	0.095	0.090	0.089	0.137	0.114	0.184	0.890	0.562	0.237	0.145	0.116
24	0.094	0.092	0.089	0.093	0.136	0.115	0.199	0.916	0.535	0.234	0.141	0.117
25	0.095	0.091	0.089	0.085	0.134	0.115	0.204	0.971	0.519	0.232	0.139	0.119
26	0.134	0.087	0.088	0.084	0.131	0.117	0.216	1.024	0.494	0.228	0.138	0.143
27	0.108	0.088	0.082	0.084	0.128	0.120	0.242	0.974	0.470	0.220	0.138	0.169
28	0.105	0.087	0.079	0.083	0.125	0.120	0.280	0.922	0.506	0.216	0.136	0.169
29	0.102	0.085	0.080	0.082		0.118	0.289	0.844	0.490	0.212	0.137	0.138
30	0.099	0.084	0.080	0.082		0.118	0.302	0.823	0.437	0.213	0.159	0.126
31	0.100		0.079	0.081		0.118		0.823		0.211	0.139	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	3.453	2.795	2.843	2.451	3.147	3.657	4.649	20.245	20.723	9.378	5.114	4.048
TOTAL FLOW (cms days)	0.098	0.079	0.081	0.069	0.089	0.104	0.132	0.573	0.587	0.266	0.145	0.115
TOTAL DEPTH (in)	0.903	0.731	0.744	0.641	0.823	0.957	1.216	5.295	5.420	2.453	1.338	1.059
TOTAL DEPTH (cm)	2.294	1.857	1.889	1.629	2.091	2.430	3.089	13.450	13.767	6.230	3.397	2.689

ANNUAL SUMMARY:
Sum of Mean Daily Flow 82.503 cfs = 2.336 cms
Total Depth 21.579 in = 54.811 cm
Maximum Instantaneous Flow 1.460 cfs = 0.041 cms on July 1 at 9.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 230
WATERSHED AREA: 91 ACRES (36 HECTARES)

WATER YEAR 1983
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.120	0.121	0.081	0.059*	0.075*	0.125*	0.128	0.310	0.197*	0.251*	0.126	0.154
2	0.118	0.114	0.082	0.057*	0.068*	0.153*	0.127	0.324	0.206*	0.224*	0.125	0.132
3	0.147	0.111	0.123	0.057*	0.067*	0.147*	0.127	0.331	0.212*	0.200*	0.122	0.114
4	0.128	0.119	0.096	0.061*	0.064*	0.168*	0.110	0.337	0.220*	0.189*	0.121	0.106
5	0.122	0.130	0.091	0.190*	0.059*	0.174*	0.110	0.384	0.225*	0.173*	0.119	0.102
6	0.117	0.145	0.089	0.150*	0.060*	0.158*	0.110	0.359	0.221*	0.161*	0.117	0.098
7	0.139	0.116	0.082*	0.266*	0.061*	0.164*	0.109	0.346	0.218*	0.156	0.122	0.093
8	0.129	0.112	0.073*	0.208*	0.061*	0.160*	0.109	0.340	0.232*	0.152	0.122	0.089
9	0.123	0.108	0.070*	0.154*	0.061*	0.169	0.108	0.306	0.221	0.158	0.128	0.089
10	0.116	0.103	0.068*	0.134*	0.060*	0.183	0.106	0.288	0.227	0.182	0.153	0.130
11	0.115	0.097	0.065*	0.119*	0.064*	0.199	0.104	0.263	0.222	0.156	0.151	0.127
12	0.114	0.091	0.064*	0.113*	0.076*	0.212	0.104	0.248	0.250	0.149	0.130	0.103
13	0.112	0.085	0.066*	0.107*	0.074*	0.229	0.102	0.241	0.219	0.146	0.124	0.100
14	0.110	0.081	0.065*	0.102*	0.072*	0.217	0.100	0.238	0.205	0.202	0.147	0.097
15	0.109	0.081	0.065*	0.097*	0.070*	0.204	0.100	0.261	0.215	0.171	0.134	0.095
16	0.107	0.089	0.077*	0.093*	0.069*	0.199	0.105	0.240	0.198	0.158	0.121	0.095
17	0.110	0.094	0.086*	0.089*	0.072*	0.194	0.122	0.254	0.204	0.152	0.112	0.094
18	0.108	0.095	0.075*	0.085*	0.159*	0.184	0.146	0.305	0.228	0.145	0.110	0.105
19	0.106	0.093	0.076*	0.082*	0.127*	0.174	0.168	0.290	0.203	0.142	0.108	0.105
20	0.105	0.091	0.075*	0.080*	0.106*	0.164	0.188	0.299	0.194	0.161	0.107	0.099
21	0.107	0.090	0.074*	0.079*	0.101*	0.157	0.205	0.315	0.188	0.143	0.106	0.098
22	0.112	0.088	0.076*	0.078*	0.117*	0.152	0.237	0.315	0.181	0.136	0.120	0.097
23	0.107	0.085	0.075*	0.077*	0.128*	0.146	0.304	0.310	0.176	0.137	0.121	0.094
24	0.103	0.087	0.072*	0.079*	0.143*	0.142	0.419	0.297	0.176	0.180	0.114	0.092
25	0.112	0.083	0.067*	0.077*	0.152*	0.141	0.412	0.284	0.174*	0.149	0.107	0.092
26	0.129	0.083	0.069*	0.076*	0.147*	0.137	0.390	0.272	0.166*	0.140	0.102	0.091
27	0.119	0.083	0.069*	0.087*	0.134*	0.134	0.344	0.262	0.189*	0.136	0.100	0.090
28	0.113	0.083	0.067*	0.087*	0.126*	0.131	0.308	0.245	0.186*	0.134	0.097	0.090
29	0.125	0.083	0.065*	0.082*		0.136	0.299	0.233	0.190*	0.132	0.094	0.090
30	0.125	0.082	0.063*	0.080*		0.162	0.305	0.219*	0.184*	0.129	0.091	0.094
31	0.121		0.060*	0.077*		0.138		0.202*		0.127	0.107	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	3.626	2.919	2.326	3.178	2.571	5.153	5.609	8.920	6.128	4.969	3.660	3.052
TOTAL FLOW (cms days)	0.103	0.083	0.066	0.090	0.073	0.146	0.159	0.253	0.174	0.141	0.104	0.086
TOTAL DEPTH (in)	0.948	0.763	0.608	0.831	0.672	1.348	1.467	2.333	1.603	1.300	0.957	0.798
TOTAL DEPTH (cm)	2.409	1.939	1.545	2.111	1.708	3.423	3.726	5.926	4.071	3.301	2.432	2.028

ANNUAL SUMMARY:
Sum of Mean Daily Flow 52.110 cfs = 1.476 cms
Total Depth 13.630 in = 34.619 cm
Maximum Instantaneous Flow 0.730 cfs = 0.021 cms on August 10 at 23.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 230
WATERSHED AREA: 91 ACRES (36 HECTARES)

WATER YEAR 1984
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.093	0.085	0.078	0.072	0.099*	0.079*	0.138*	0.429*	1.406	0.449	0.205	0.127
2	0.090	0.100	0.077	0.084	0.095*	0.079*	0.138*	0.443*	1.319	0.433	0.206	0.116
3	0.087	0.092	0.077	0.189	0.090	0.079*	0.137*	0.360*	1.265	0.415	0.198	0.114
4	0.084	0.112	0.077	0.151	0.090	0.078*	0.142*	0.319*	1.261	0.404	0.193	0.110
5	0.082	0.094	0.078	0.141	0.089	0.078*	0.166*	0.306*	1.222	0.392	0.192	0.098*
6	0.080	0.135	0.079	0.137	0.087	0.078*	0.167*	0.298*	1.213	0.380	0.199	0.133*
7	0.079	0.102	0.078*	0.122	0.087	0.078*	0.153*	0.310*	1.223	0.368	0.191	0.117*
8	0.081	0.097	0.079*	0.116	0.087	0.078*	0.157*	0.332*	1.175	0.354	0.184	0.136*
9	0.111	0.092	0.080*	0.110	0.086	0.077*	0.159*	0.431*	1.139*	0.339	0.180	0.123*
10	0.095	0.092	0.079*	0.105	0.086	0.078*	0.156*	0.384*	1.069*	0.331	0.177	0.116*
11	0.090	0.112	0.080*	0.103	0.084	0.089*	0.152*	0.422*	1.086*	0.322	0.176	0.112*
12	0.087	0.106	0.080*	0.102	0.083	0.095*	0.151*	0.564*	1.046*	0.313	0.176	0.110*
13	0.087	0.102	0.081*	0.101	0.101	0.095*	0.153*	0.689*	1.022*	0.307	0.174	0.110*
14	0.087	0.097	0.080*	0.100	0.094	0.114	0.195*	0.864*	0.995*	0.299	0.169	0.108*
15	0.087	0.099	0.078*	0.096	0.089	0.104	0.280*	0.841*	0.975*	0.291	0.165	0.110*
16	0.086	0.101	0.077	0.092	0.087	0.105	0.364*	0.829*	0.940*	0.283	0.167	0.110*
17	0.097	0.105	0.078	0.090	0.086	0.106	0.453*	0.849*	0.885*	0.277	0.188	0.107*
18	0.097	0.100	0.077	0.088*	0.085	0.102	0.506*	0.953*	0.816*	0.276	0.178	0.104*
19	0.088	0.096	0.077	0.087*	0.085	0.116	0.478*	1.015*	0.738*	0.269	0.165	0.102*
20	0.086	0.092	0.076	0.085*	0.084	0.172*	0.456*	1.194*	0.694*	0.258	0.163	0.188*
21	0.086	0.086	0.074	0.083*	0.084	0.155*	0.444*	1.160*	0.665*	0.252	0.159	0.148*
22	0.106	0.078	0.073	0.081*	0.083	0.140*	0.476*	1.251*	0.564*	0.242	0.156	0.136*
23	0.107	0.085	0.073	0.078*	0.083	0.140*	0.479*	1.432*	0.498*	0.234	0.156	0.133*
24	0.090	0.093	0.074	0.167*	0.082	0.145*	0.451*	1.326*	0.456*	0.235	0.154	0.132*
25	0.088	0.092	0.072	0.138*	0.082	0.144*	0.442*	1.309*	0.413*	0.229	0.152	0.128*
26	0.086	0.090	0.070	0.104*	0.084	0.143*	0.433*	1.147*	0.363*	0.315	0.151	0.127*
27	0.084	0.088	0.066	0.097*	0.082	0.141*	0.425*	0.970*	0.325*	0.247	0.142	0.125*
28	0.079	0.088	0.066	0.096*	0.081	0.140*	0.420*	1.058*	0.407*	0.276	0.130	0.122*
29	0.078	0.079	0.067	0.095*	0.081*	0.139*	0.417*	1.292*	0.490	0.243	0.114	0.125*
30	0.079	0.077	0.067	0.099*		0.139*	0.412*	1.659	0.471	0.233	0.131	0.121*
31	0.079		0.073	0.099*		0.139*		1.577		0.213	0.155	

MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	2.732	2.866	2.339	3.306	2.515	3.443	9.101	26.012	26.141	9.474	5.243	3.646
TOTAL FLOW (cms days)	0.077	0.081	0.066	0.094	0.071	0.098	0.258	0.737	0.740	0.268	0.148	0.103
TOTAL DEPTH (in)	0.714	0.750	0.612	0.865	0.658	0.901	2.380	6.804	6.837	2.478	1.371	0.954
TOTAL DEPTH (cm)	1.815	1.904	1.554	2.196	1.671	2.288	6.046	17.281	17.367	6.294	3.483	2.422

ANNUAL SUMMARY:
Sum of Mean Daily Flow 96.819 cfs = 2.742 cms
Total Depth 25.324 in = 64.322 cm
Maximum Instantaneous Flow 2.120 cfs = 0.060 cms on May 30 at 12.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 230
WATERSHED AREA: 91 ACRES (36 HECTARES)

WATER YEAR 1985
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.114	0.089*	0.077	0.081	0.082*	0.089	0.099	0.469*	0.255	0.150	0.174	0.080
2	0.115	0.127*	0.074	0.081	0.082*	0.087	0.108	0.617*	0.266	0.147	0.190	0.081
3	0.114	0.130*	0.125	0.082*	0.082*	0.084	0.100	0.652*	0.243	0.145	0.130	0.080
4	0.113	0.114*	0.208	0.082*	0.083*	0.081	0.092	0.563*	0.243	0.143	0.130	0.080
5	0.119	0.108*	0.167	0.082*	0.084*	0.078	0.093	0.438*	0.289	0.139	0.124	0.079
6	0.115	0.136*	0.090	0.082*	0.089*	0.075	0.096	0.364*	0.271	0.138	0.114	0.108
7	0.113	0.122*	0.075	0.082*	0.089	0.072	0.110	0.344*	0.263	0.143	0.112	0.141
8	0.110	0.098	0.072	0.082*	0.089	0.069	0.141	0.343*	0.272	0.139	0.114	0.255
9	0.109	0.093	0.072	0.081*	0.089	0.066	0.148	0.328*	0.252	0.134	0.108	0.184
10	0.107	0.091	0.072	0.081*	0.089	0.065*	0.172	0.330	0.249	0.142	0.123	0.203
11	0.123	0.089	0.072	0.082*	0.089	0.063*	0.219	0.317	0.241	0.132	0.124	0.204
12	0.116	0.096	0.073*	0.082*	0.089	0.062*	0.197	0.285	0.234	0.130	0.131	0.235
13	0.137	0.120	0.073*	0.082*	0.089	0.062*	0.224	0.268	0.224	0.127	0.116	0.156
14	0.111	0.101	0.074*	0.082*	0.089	0.062*	0.276	0.276	0.211	0.127	0.108	0.146
15	0.104*	0.087	0.074*	0.082*	0.089	0.062*	0.345	0.271	0.205	0.125	0.103	0.170
16	0.095*	0.089	0.076*	0.082*	0.089	0.062*	0.389	0.276	0.201	0.125	0.099	0.149
17	0.086*	0.090	0.077*	0.082*	0.089	0.063*	0.394	0.282	0.195	0.123	0.096	0.185
18	0.086*	0.090	0.078*	0.082*	0.088	0.063*	0.359	0.278	0.189	0.122	0.093	0.148
19	0.086*	0.088	0.080	0.082*	0.088	0.061*	0.319	0.270	0.184	0.121	0.091	0.140
20	0.083*	0.088	0.080	0.082*	0.088	0.062*	0.276	0.256	0.181	0.119	0.091	0.135
21	0.081*	0.089	0.079	0.081*	0.088	0.066	0.255*	0.240	0.177	0.117	0.140	0.129
22	0.079*	0.088	0.082	0.081*	0.088	0.066	0.240*	0.226	0.176	0.117	0.113	0.123
23	0.079*	0.086	0.082	0.081*	0.088	0.066	0.226*	0.217	0.173	0.116	0.102	0.117
24	0.079*	0.087	0.082	0.081*	0.088	0.067	0.212*	0.223	0.167	0.116	0.096	0.113
25	0.095*	0.086	0.081	0.082*	0.088	0.068	0.199*	0.217	0.167	0.114	0.091	0.108
26	0.109*	0.080	0.081	0.082*	0.087	0.068	0.185*	0.201	0.165	0.112	0.088	0.105
27	0.096*	0.078	0.081	0.083*	0.088	0.068	0.227*	0.195	0.161	0.111	0.086	0.101
28	0.093*	0.079	0.081	0.083*	0.088	0.068	0.238*	0.224	0.159	0.110	0.083	0.099
29	0.090*	0.079	0.081	0.082*		0.068	0.288*	0.259	0.158	0.120	0.083	0.094
30	0.089*	0.079	0.081	0.082*		0.068	0.353*	0.264	0.154	0.118	0.083	0.087
31	0.088*		0.081	0.081*		0.090		0.238		0.130	0.081	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	3.134	2.874	2.679	2.535	2.446	2.149	6.581	9.729	6.324	3.952	3.417	4.035
TOTAL FLOW (cms days)	0.089	0.081	0.076	0.072	0.069	0.061	0.186	0.276	0.179	0.112	0.097	0.114
TOTAL DEPTH (in)	0.820	0.752	0.701	0.663	0.640	0.562	1.721	2.545	1.654	1.034	0.894	1.055
TOTAL DEPTH (cm)	2.082	1.910	1.780	1.684	1.625	1.428	4.372	6.464	4.202	2.626	2.270	2.680

ANNUAL SUMMARY:
Sum of Mean Daily Flow 49.856 cfs = 1.412 cms
Total Depth 13.040 in = 33.122 cm
Maximum Instantaneous Flow 0.890 cfs = 0.025 cms on September 8 at 20.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 233
WATERSHED AREA: 81 ACRES (32 HECTARES)

WATER YEAR 1979
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.014	0.014	0.009	0.009	0.009	0.012	0.045	0.675	0.176	0.043	0.011	0.014
2	0.014	0.014	0.009	0.009	0.009	0.012	0.044	0.722	0.163	0.038	0.011	0.012
3	0.014	0.014	0.009	0.009	0.009	0.012	0.043	0.730	0.151	0.036	0.011	0.010
4	0.014	0.016	0.016	0.009	0.009	0.012	0.041	0.812	0.140	0.035	0.011	0.010
5	0.014	0.012	0.009	0.009	0.009	0.019	0.050	0.985	0.131	0.032	0.011	0.009
6	0.014	0.012	0.009	0.009	0.009	0.052	0.061	1.006	0.128	0.031	0.011	0.009
7	0.014	0.012	0.009	0.009	0.009	0.058	0.075	0.884	0.100	0.030	0.010	0.009
8	0.014	0.091	0.009	0.009	0.009	0.038	0.070	0.750	0.091	0.027	0.010	0.008
9	0.014	0.023	0.009	0.009	0.008	0.032	0.083	0.648	0.083	0.026	0.010	0.009
10	0.014	0.014	0.009	0.009	0.011	0.029	0.082	0.576	0.078	0.025	0.010	0.011
11	0.014	0.009	0.009	0.009	0.014	0.027	0.082	0.524	0.072	0.024	0.009	0.009
12	0.013	0.009	0.009	0.009	0.029	0.027	0.082	0.500	0.067	0.024	0.010	0.007
13	0.012	0.009	0.009	0.009	0.062	0.026	0.079	0.512	0.063	0.023	0.010	0.007
14	0.012	0.009	0.009	0.009	0.028	0.025	0.075	0.543	0.060	0.021	0.011	0.007
15	0.011	0.009	0.009	0.009	0.018	0.025	0.077	0.609	0.057	0.020	0.018	0.006
16	0.011	0.009	0.009	0.009	0.016	0.029	0.096	0.648	0.055	0.019	0.011	0.006
17	0.012	0.009	0.009	0.009	0.014	0.029	0.124	0.634	0.057	0.018	0.011	0.006
18	0.011	0.009	0.009	0.009	0.015	0.027	0.113	0.595	0.066	0.017	0.011	0.005
19	0.011	0.009	0.009	0.009	0.014	0.027	0.115	0.540	0.057	0.017	0.012	0.005
20	0.012	0.009	0.009	0.009	0.013	0.027	0.114	0.498	0.052	0.016	0.010	0.005
21	0.012	0.009	0.009	0.009	0.013	0.027	0.112	0.461	0.192	0.016	0.011	0.005
22	0.012	0.009	0.009	0.009	0.013	0.026	0.128	0.428	0.066	0.021	0.010	0.005
23	0.012	0.009	0.009	0.009	0.013	0.025	0.132	0.403	0.057	0.017	0.043	0.005
24	0.013	0.009	0.009	0.009	0.012	0.026	0.143	0.389	0.053	0.015	0.021	0.005
25	0.012	0.009	0.009	0.009	0.012	0.027	0.161	0.343	0.049	0.015	0.011	0.005
26	0.012	0.009	0.009	0.009	0.012	0.027	0.188	0.313	0.045	0.014	0.011	0.005
27	0.012	0.009	0.009	0.009	0.012	0.035	0.240	0.287	0.043	0.014	0.011	0.005
28	0.012	0.009	0.009	0.009	0.012	0.055	0.322	0.264	0.040	0.015	0.010	0.005
29	0.013	0.009	0.009	0.009		0.049	0.460	0.234	0.038	0.014	0.017	0.005
30	0.013	0.009	0.009	0.009		0.044	0.588	0.214	0.041	0.012	0.040	0.005
31	0.012		0.009	0.009		0.044		0.193		0.012	0.034	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	0.392	0.405	0.292	0.285	0.414	0.927	4.021	16.916	2.468	0.684	0.436	0.214
TOTAL FLOW (cms days)	0.011	0.011	0.008	0.008	0.012	0.026	0.114	0.479	0.070	0.019	0.012	0.006
TOTAL DEPTH (in)	0.115	0.119	0.086	0.084	0.122	0.272	1.182	4.971	0.725	0.201	0.128	0.063
TOTAL DEPTH (cm)	0.293	0.302	0.218	0.213	0.309	0.692	3.001	12.626	1.842	0.511	0.325	0.160

ANNUAL SUMMARY:
Sum of Mean Daily Flow 27.455 cfs = 0.778 cms
Total Depth 8.067 in = 20.491 cm
Maximum Instantaneous Flow 2.120 cfs = 0.060 cms on June 21 at 13.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 233
WATERSHED AREA: 81 ACRES (32 HECTARES)

WATER YEAR 1980
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.008	0.022*	0.017*	0.015*	0.011	0.039	0.022	0.270*	0.271	0.149	0.050*	0.019
2	0.008	0.023*	0.028*	0.015*	0.011	0.039	0.022	0.378*	0.274	0.204	0.047*	0.045
3	0.008	0.024*	0.032*	0.015*	0.020	0.044	0.022	0.447*	0.247	0.185	0.045*	0.021
4	0.008	0.025*	0.038*	0.014*	0.013	0.048	0.023	0.374*	0.278	0.168	0.043*	0.018
5	0.008	0.027*	0.024*	0.014*	0.011	0.041	0.028	0.335*	0.271	0.168	0.041*	0.014
6	0.008	0.024*	0.021*	0.014*	0.011	0.038	0.026	0.276*	0.280	0.167	0.039*	0.013
7	0.008	0.021*	0.024*	0.013*	0.010	0.037	0.025	0.237*	0.259	0.148*	0.038*	0.011
8	0.008	0.020*	0.023*	0.012	0.010	0.035	0.025	0.236*	0.242	0.144*	0.037*	0.010
9	0.C08	0.020*	0.024*	0.012	0.010	0.033	0.030	0.228	0.237	0.178*	0.036*	0.009
10	0.008	0.018*	0.029*	0.011	0.010	0.034	0.029	0.207	0.241	0.140*	0.035*	0.025
11	0.008	0.018*	0.020*	0.011	0.009	0.033	0.029*	0.182	0.257	0.130*	0.034*	0.036
12	0.008	0.015*	0.019*	0.023	0.009	0.030	0.030*	0.164	0.262	0.123*	0.032*	0.019
13	0.008	0.016*	0.019*	0.028	0.010	0.029	0.044*	0.152	0.235	0.117*	0.030*	0.038
14	0.008	0.014*	0.019*	0.035	0.010	0.028	0.062*	0.140	0.256	0.140*	0.029	0.026
15	0.021	0.014*	0.020*	0.022	0.010	0.028	0.061*	0.151	0.251	0.116*	0.026	0.019
16	0.013	0.017*	0.019*	0.018	0.010	0.028	0.060*	0.136	0.243	0.108*	0.023	0.014
17	0.021	0.032*	0.037*	0.017	0.011	0.028	0.091*	0.120	0.242	0.101*	0.020	0.011
18	0.033	0.021*	0.027*	0.016	0.017	0.028	0.118*	0.111	0.239	0.096*	0.069	0.044
19	0.059	0.018*	0.022*	0.015	0.020	0.029	0.159*	0.102	0.228	0.092*	0.030	0.027
20	0.032	0.016*	0.020*	0.015	0.019	0.028	0.214*	0.096	0.216	0.089*	0.028	0.099
21	0.032	0.015*	0.018*	0.015	0.017	0.028	0.235*	0.102	0.202	0.085*	0.026	0.064
22	0.036	0.016*	0.017*	0.015	0.018	0.028	0.276*	0.105	0.201	0.081*	0.024	0.036
23	0.040	0.017*	0.015*	0.015	0.020	0.027	0.314*	0.109	0.182	0.076*	0.023	0.032
24	0.032	0.018*	0.015*	0.014	0.018	0.026	0.340*	0.109	0.167	0.073*	0.021	0.028
25	0.034	0.019*	0.015*	0.013	0.020	0.024	0.326*	0.181	0.155	0.070*	0.020	0.025
26	0.030	0.018*	0.015*	0.012	0.028	0.023	0.318*	0.209	0.170	0.065*	0.019	0.023
27	0.029	0.017*	0.014*	0.011	0.044	0.024	0.335*	0.220	0.156	0.063*	0.020	0.021
28	0.028	0.017*	0.014*	0.011	0.058	0.024	0.359*	0.253	0.134	0.060*	0.018	0.019
29	0.028	0.017*	0.013*	0.011	0.044	0.024	0.345*	0.261	0.124	0.057*	0.017	0.018
30	0.026*	0.017*	0.013*	0.011		0.023	0.290*	0.281	0.117	0.055*	0.016	0.013
31	0.023*		0.015*	0.010		0.023		0.261		0.053*	0.023	

MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	0.624	0.576	0.647	0.474	0.508	0.952	4.258	6.434	6.635	3.499	0.960	0.795
TOTAL FLOW (cms days)	0.018	0.016	0.018	0.013	0.014	0.027	0.121	0.182	0.188	0.099	0.027	0.023
TOTAL DEPTH (in)	0.183	0.169	0.190	0.139	0.149	0.280	1.251	1.891	1.950	1.028	0.282	0.233
TOTAL DEPTH (cm)	0.466	0.430	0.483	0.354	0.379	0.711	3.178	4.802	4.952	2.612	0.717	0.593

ANNUAL SUMMARY:
Sum of Mean Daily Flow 26.362 cfs = 0.747 cms
Total Depth 7.746 in = 19.676 cm
Maximum Instantaneous Flow 0.600 cfs = 0.017 cms on July 2 at 21.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 233
WATERSHED AREA: 81 ACRES (32 HECTARES)

WATER YEAR 1981
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.009	0.004	0.009	0.216	0.050*	0.100*	0.146*	0.246	0.224*	0.209	0.045	0.030
2	0.008	0.016	0.018	0.196	0.045*	0.100*	0.144*	0.235	0.222*	0.192	0.043	0.026
3	0.007	0.010	0.026	0.181	0.045*	0.100*	0.142	0.224	0.220*	0.177	0.042	0.023
4	0.007	0.007	0.028	0.162	0.043*	0.100*	0.135	0.218	0.225*	0.163	0.042*	0.022
5	0.006	0.005	0.019	0.148	0.043*	0.100*	0.137	0.203	0.278*	0.151	0.041*	0.020
6	0.006	0.033	0.017	0.134	0.043*	0.100*	0.127	0.179	0.257*	0.193	0.040*	0.019
7	0.006	0.072	0.014	0.123	0.043*	0.100*	0.122	0.165	0.261*	0.187	0.039*	0.019
8	0.006	0.038	0.010	0.111	0.043*	0.100*	0.118	0.153	0.380*	0.143	0.038*	0.018
9	0.006	0.039	0.007	0.102	0.042*	0.098*	0.115	0.143	0.362*	0.131	0.037*	0.019
10	0.005	0.031	0.006	0.094	0.036*	0.097*	0.110	0.138	0.385*	0.121	0.034*	0.019
11	0.005	0.025	0.005	0.088	0.035*	0.097*	0.107	0.146	0.392	0.113	0.031*	0.017
12	0.013	0.021	0.005	0.083	0.047*	0.096*	0.104	0.127	0.452	0.106	0.030*	0.016
13	0.012	0.014	0.005	0.078	0.052*	0.096*	0.097	0.115	0.440	0.099	0.029*	0.018
14	0.008	0.009	0.005	0.073	0.073*	0.096*	0.100	0.117	0.497	0.094	0.029*	0.018
15	0.006	0.006	0.020	0.062	0.051*	0.095*	0.119	0.125	0.482	0.090	0.028*	0.015
16	0.005	0.005	0.021	0.052	0.102*	0.099*	0.122	0.121*	0.566	0.085	0.027*	0.014
17	0.005	0.004	0.023	0.055	0.066*	0.094*	0.123	0.136*	0.525	0.082	0.026*	0.014
18	0.005	0.004	0.019	0.058	0.063*	0.092*	0.146	0.150*	0.559	0.080	0.026*	0.013
19	0.005	0.004	0.018	0.056	0.093*	0.095*	0.184	0.166*	0.615	0.076	0.031*	0.025
20	0.005	0.004	0.018	0.054	0.100*	0.101*	0.204	0.246*	0.601	0.068	0.026*	0.020
21	0.005	0.009	0.034	0.053	0.100*	0.097*	0.228	0.238*	0.574	0.066	0.024*	0.021
22	0.004	0.017	0.109	0.053*	0.101*	0.102*	0.248	0.251*	0.549	0.062	0.023*	0.018
23	0.004	0.010	0.056	0.102*	0.101*	0.101*	0.267	0.249*	0.499	0.059	0.022*	0.016
24	0.004	0.007	0.061	0.071*	0.100*	0.100*	0.289	0.259*	0.444	0.057	0.021*	0.015
25	0.005	0.005	0.220	0.057*	0.099*	0.136*	0.282	0.257*	0.397	0.067	0.021*	0.027
26	0.015	0.004	0.448	0.053*	0.100*	0.125*	0.280	0.249*	0.359	0.058	0.020*	0.021
27	0.008	0.012	0.476	0.053*	0.100*	0.123*	0.274	0.248*	0.324	0.055	0.021*	0.060
28	0.006	0.016	0.398	0.053*	0.100*	0.127*	0.272	0.245*	0.290	0.053	0.021*	0.037
29	0.005	0.013	0.337	0.052*		0.134*	0.260	0.238*	0.257	0.051	0.018*	0.024
30	0.004	0.012	0.306	0.051*		0.131*	0.253	0.276*	0.226	0.049	0.049*	0.022
31	0.004		0.246	0.051*		0.138*		0.236*		0.048	0.025*	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	0.199	0.452	2.982	2.774	1.913	3.270	5.256	6.100	11.861	3.182	0.947	0.645
TOTAL FLOW (cms days)	0.006	0.013	0.084	0.079	0.054	0.093	0.149	0.173	0.336	0.090	0.027	0.018
TOTAL DEPTH (in)	0.058	0.133	0.876	0.815	0.562	0.961	1.544	1.792	3.485	0.935	0.278	0.190
TOTAL DEPTH (cm)	0.148	0.337	2.226	2.070	1.427	2.440	3.923	4.553	8.853	2.375	0.707	0.481

ANNUAL SUMMARY:

Sum of Mean Daily Flow 39.579 cfs = 1.121 cms
Total Depth 11.630 in = 29.541 cm
Maximum Instantaneous Flow 1.130 cfs = 0.032 cms on May 22 at 24.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 233
WATERSHED AREA: 81 ACRES (32 HECTARES)

WATER YEAR 1982
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.020	0.019	0.023	0.021*	0.019*	0.080*	0.068*	0.367*	0.633	0.200	0.061	0.026
2	0.021	0.018	0.024	0.021*	0.018*	0.081*	0.068*	0.560*	0.618	0.148	0.058	0.026
3	0.020	0.017	0.021	0.021*	0.019*	0.080*	0.068*	0.683*	0.643	0.134	0.058	0.031
4	0.019	0.016	0.016	0.021*	0.019*	0.079*	0.069*	0.674*	0.618	0.131	0.056	0.030
5	0.019	0.015	0.022	0.021*	0.019*	0.073*	0.069*	0.631	0.585	0.132	0.060	0.029
6	0.019	0.014	0.048	0.021*	0.019*	0.070	0.069*	0.572	0.563	0.117	0.056	0.028
7	0.021	0.013	0.029	0.022*	0.019*	0.069	0.069*	0.558	0.551	0.122	0.052	0.028
8	0.022	0.013	0.024	0.021*	0.018*	0.068	0.068*	0.519	0.502	0.124	0.051	0.027
9	0.045	0.013	0.027	0.021*	0.018*	0.087	0.069*	0.537	0.473	0.123	0.050	0.027
10	0.047	0.013	0.031	0.021*	0.018*	0.086	0.074*	0.539	0.451	0.111	0.049	0.081
11	0.049	0.012	0.024	0.021*	0.018*	0.085	0.117*	0.528	0.436	0.102	0.046	0.043
12	0.032	0.012	0.019	0.020*	0.017*	0.084	0.138*	0.532	0.417	0.096	0.045	0.056
13	0.025	0.033	0.020	0.020*	0.017*	0.083	0.115*	0.574	0.397	0.142	0.043	0.046
14	0.023	0.023	0.020	0.020*	0.125*	0.088	0.113*	0.696	0.377	0.110	0.041	0.038
15	0.022	0.022	0.019	0.020*	0.079*	0.094	0.103*	0.885	0.346	0.099	0.041	0.033
16	0.020	0.019	0.018	0.019*	0.097*	0.093	0.100*	1.057	0.320	0.100	0.039	0.030
17	0.020	0.027	0.017	0.020*	0.083*	0.092	0.098*	1.191	0.292	0.091	0.038	0.028
18	0.019	0.039	0.015	0.019*	0.083*	0.092	0.098*	1.317	0.265	0.086	0.037	0.027
19	0.018	0.023	0.066	0.019*	0.083*	0.090	0.097*	1.310	0.241	0.083	0.041	0.027
20	0.017	0.021	0.034	0.019*	0.083*	0.088	0.096*	1.184	0.222	0.080	0.063	0.027
21	0.016	0.020	0.027	0.019*	0.083*	0.086	0.103*	1.106	0.206	0.078	0.057	0.027
22	0.016	0.035	0.026	0.019*	0.083*	0.084	0.135*	1.170	0.191	0.075	0.049	0.028
23	0.015	0.024	0.024	0.019*	0.083*	0.083	0.171*	1.250	0.178	0.071	0.049	0.028
24	0.015	0.022	0.023	0.019*	0.084*	0.081	0.179*	1.260	0.165	0.069	0.048	0.028
25	0.015	0.022	0.023	0.019*	0.084*	0.079	0.177*	1.290	0.156	0.069	0.048	0.027
26	0.038	0.049	0.023	0.018*	0.083*	0.079	0.191*	1.330	0.143	0.066	0.048	0.081
27	0.023	0.034	0.022	0.019*	0.082*	0.080	0.222*	1.233	0.134	0.062	0.049	0.097
28	0.020	0.024	0.021	0.018*	0.081*	0.076*	0.228*	1.052	0.169	0.060	0.040	0.099
29	0.019	0.023	0.021*	0.018*		0.075*	0.229*	0.879	0.163	0.059	0.031	0.071
30	0.019	0.023	0.021*	0.019*		0.073*	0.253*	0.755	0.135	0.059	0.057	0.054
31	0.018		0.021*	0.019*		0.071*		0.671		0.057	0.043	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	0.709	0.660	0.769	0.612	1.531	2.527	3.654	26.907	10.589	3.056	1.502	1.227
TOTAL FLOW (cms days)	0.020	0.019	0.022	0.017	0.043	0.072	0.103	0.762	0.300	0.087	0.043	0.035
TOTAL DEPTH (in)	0.208	0.194	0.226	0.180	0.450	0.743	1.074	7.906	3.112	0.898	0.441	0.361
TOTAL DEPTH (cm)	0.529	0.493	0.574	0.456	1.143	1.886	2.727	20.082	7.904	2.281	1.121	0.916

ANNUAL SUMMARY:

Sum of Mean Daily Flow 53.742 cfs = 1.522 cms
Total Depth 15.792 in = 40.112 cm
Maximum Instantaneous Flow 1.360 cfs = 0.039 cms on May 25 at 14.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 233
WATERSHED AREA: 81 ACRES (32 HECTARES)

WATER YEAR 1983
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.029	0.029	0.009	0.009*	0.025	0.117	0.107	0.253	0.137	0.083	0.023*	0.047*
2	0.023	0.027	0.009	0.008*	0.024	0.138	0.105	0.250	0.132	0.065	0.022*	0.032*
3	0.064	0.024	0.013	0.008*	0.023	0.132	0.099	0.245	0.123	0.053	0.020*	0.022*
4	0.041	0.021	0.061	0.010*	0.022	0.145	0.092	0.244	0.116	0.047	0.018	0.018*
5	0.032	0.020	0.038	0.086*	0.023	0.159	0.091	0.283	0.109	0.040	0.018	0.015*
6	0.028	0.051	0.030	0.058*	0.022	0.180	0.091	0.256	0.102	0.030	0.017	0.013*
7	0.061	0.037	0.025	0.135*	0.022	0.200	0.091	0.240	0.096	0.021	0.027	0.011*
8	0.052	0.030	0.023	0.095*	0.022	0.202	0.091	0.246	0.094	0.019	0.050	0.008
9	0.042	0.025	0.020	0.061*	0.022	0.215	0.089	0.233	0.077	0.020	0.057	0.007
10	0.034	0.022	0.018	0.048*	0.022	0.242	0.089	0.224	0.084	0.046	0.072*	0.038
11	0.030	0.020	0.016	0.040*	0.023	0.286	0.085	0.211	0.078	0.031	0.065*	0.041
12	0.026	0.018	0.015	0.039*	0.025	0.325	0.083	0.200	0.095	0.024	0.051*	0.028
13	0.024	0.016	0.014	0.036*	0.026	0.349	0.080	0.192	0.075	0.021	0.043*	0.021
14	0.022	0.015	0.013	0.035*	0.028	0.326	0.077	0.184	0.067	0.066	0.053*	0.016
15	0.020	0.013	0.014	0.033*	0.029	0.301	0.075	0.201	0.074	0.043	0.055*	0.013
16	0.019	0.012	0.015	0.032*	0.030	0.277	0.076	0.187	0.062	0.038	0.043*	0.011
17	0.016	0.011	0.014	0.032*	0.032	0.257	0.085	0.186	0.075	0.032	0.036*	0.009
18	0.015	0.011	0.014	0.032*	0.106	0.236	0.104	0.207	0.075	0.027	0.030*	0.009
19	0.014	0.010	0.014	0.031*	0.071	0.214	0.128	0.191	0.063	0.024	0.028*	0.008
20	0.013	0.010	0.014	0.031*	0.064	0.192	0.151	0.189	0.058	0.040	0.028*	0.007
21	0.013	0.010	0.013	0.031*	0.065	0.178	0.177	0.189	0.054	0.039	0.027*	0.007
22	0.012	0.010	0.013	0.033*	0.075	0.170	0.224	0.189	0.052	0.031	0.034*	0.006
23	0.012	0.010	0.014	0.033*	0.081	0.160	0.305	0.187	0.050	0.028	0.034*	0.006
24	0.012	0.010	0.014	0.032*	0.088	0.147	0.386	0.185	0.045	0.049	0.031*	0.005
25	0.012	0.010	0.014	0.031*	0.098	0.141	0.388	0.181	0.041	0.048*	0.027*	0.006
26	0.014	0.010	0.013	0.030	0.103	0.132	0.366	0.176	0.037	0.040*	0.024*	0.005
27	0.016	0.010	0.013*	0.029	0.105	0.125	0.333	0.171	0.048	0.035*	0.023*	0.005
28	0.016	0.010	0.011*	0.028	0.108	0.117	0.303	0.165	0.046	0.032*	0.021*	0.005
29	0.033	0.010	0.011*	0.028		0.118	0.278	0.156	0.049	0.030*	0.020*	0.005
30	0.044	0.009	0.010*	0.027		0.135	0.263	0.147	0.045	0.028*	0.018*	0.005
31	0.034		0.009*	0.026		0.115		0.143		0.026*	0.025*	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	0.820	0.516	0.519	1.187	1.384	6.031	4.911	6.309	2.258	1.153	1.040	0.430
TOTAL FLOW (cms days)	0.023	0.015	0.015	0.034	0.039	0.171	0.139	0.179	0.064	0.033	0.029	0.012
TOTAL DEPTH (in)	0.241	0.152	0.153	0.349	0.407	1.772	1.443	1.854	0.663	0.339	0.306	0.126
TOTAL DEPTH (cm)	0.612	0.385	0.388	0.886	1.033	4.501	3.665	4.709	1.685	0.861	0.776	0.321

ANNUAL SUMMARY:
Sum of Mean Daily Flow 26.559 cfs = 0.752 **cms**
Total Depth 7.804 in = 19.823 **cm**
Maximum Instantaneous Flow 0.500 cfs = 0.014 **cms on August 10 at 23.00 hours**

*** Indicates some data were estimated during this day.**

HORSE CREEK STUDY AREA
WATERSHED: 233
WATERSHED AREA: 81 ACRES (32 HECTARES)

WATER YEAR 1984
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.005	0.010	0.040	0.010	0.054*	0.022	0.131	0.379*	1.000	0.133	0.041	0.052
2	0.005	0.010	0.027	0.009	0.054*	0.025	0.124	0.383*	0.857	0.125	0.035	0.044
3	0.005	0.009	0.019	0.110	0.054	0.025	0.119	0.377	0.746	0.119	0.031	0.038
4	0.005	0.035	0.015	0.078	0.053	0.025	0.116	0.355	0.683	0.113	0.029	0.032
5	0.006	0.032	0.011	0.079	0.051	0.023	0.135	0.344	0.621	0.108	0.027	0.029
6	0.006	0.054	0.009	0.081	0.048	0.022	0.136	0.338	0.579	0.102	0.026	0.056
7	0.006	0.037	0.008	0.072	0.044	0.021	0.122	0.327	0.568	0.097	0.024	0.045
8	0.005	0.028	0.006	0.069	0.039	0.021	0.130	0.337	0.539	0.091	0.022	0.041
9	0.032	0.021	0.006	0.066	0.034	0.022	0.136	0.457	0.528	0.087	0.021	0.040
10	0.030	0.017	0.029	0.062	0.030	0.022	0.135	0.469	0.512	0.082	0.020	0.034
11	0.023	0.027	0.029	0.059	0.027	0.061	0.136	0.565	0.518	0.077	0.019	0.030
12	0.019	0.038	0.021	0.055	0.024	0.056	0.138	0.701	0.469	0.073	0.019	0.026
13	0.017	0.039	0.016	0.051	0.054	0.060	0.139	0.901	0.428	0.070	0.018	0.023
14	0.015	0.028	0.013	0.048	0.056	0.089	0.147	1.318	0.405	0.067	0.018	0.021
15	0.013	0.022	0.011	0.046*	0.046	0.079	0.199	1.490	0.384	0.064	0.017	0.019
16	0.011	0.019	0.011	0.045*	0.039	0.089	0.282	1.335	0.360	0.061	0.018	0.018
17	0.020	0.017	0.010	0.044*	0.034	0.090	0.510	1.152	0.329	0.057	0.041	0.016
18	0.037	0.015	0.010	0.044*	0.030	0.090	0.781	1.034	0.302	0.057	0.045	0.015
19	0.028	0.013	0.009	0.043*	0.029	0.108	0.917	1.007	0.279	0.053	0.038	0.015
20	0.022	0.011	0.009	0.043*	0.027	0.166	0.874	1.193	0.275	0.047	0.033	0.081
21	0.019	0.010	0.009	0.041*	0.026	0.167	0.754	1.216	0.294	0.043	0.029	0.055
22	0.024	0.040	0.010	0.040*	0.025	0.184	0.688	1.122	0.240	0.041	0.027	0.048
23	0.040	0.027	0.011	0.039*	0.025	0.197	0.678	1.150	0.216	0.039	0.025	0.044
24	0.031	0.020	0.012	0.105*	0.024	0.203	0.645	1.114	0.207	0.053	0.024	0.042
25	0.025	0.016	0.011	0.082*	0.025	0.189	0.634*	1.025	0.197	0.047	0.022	0.038
26	0.021	0.013	0.011	0.057*	0.024	0.177	0.588*	1.004	0.182	0.048	0.017	0.035
27	0.018	0.011	0.011	0.054*	0.024	0.167	0.544*	0.954	0.161	0.073	0.017	0.031
28	0.015	0.010	0.011	0.054*	0.023	0.160	0.501*	0.957	0.154	0.055	0.017	0.030
29	0.014	0.032	0.011	0.053*	0.022	0.151	0.460*	1.007	0.149	0.053	0.017	0.028
30	0.012	0.065	0.011	0.052*		0.145	0.414*	1.157	0.141	0.056	0.016	0.025
31	0.011		0.011	0.053*		0.137		1.128		0.052	0.062	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	0.538	0.727	0.427	1.741	1.042	2.991	11.312	26.296	12.321	2.243	0.814	1.050
TOTAL FLOW (cms days)	0.015	0.021	0.012	0.049	0.030	0.085	0.320	0.745	0.349	0.064	0.023	0.030
TOTAL DEPTH (in)	0.158	0.214	0.126	0.511	0.306	0.879	3.324	7.727	3.621	0.659	0.239	0.309
TOTAL DEPTH (cm)	0.401	0.542	0.319	1.299	0.778	2.232	8.443	19.627	9.196	1.674	0.608	0.784

ANNUAL SUMMARY:
Sum of Mean Daily Flow 61.502 cfs = 1.742 cms
Total Depth 18.072 in = 45.903 cm
Maximum Instantaneous Flow 1.570 cfs = 0.044 cms on May 15 at 2.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 233
WATERSHED AREA: 81 ACRES (32 HECTARES)

WATER YEAR 1985
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.022	0.030	0.035	0.014	0.011*	0.007*	0.048	0.424	0.183	0.046	0.032	0.014
2	0.020	0.056	0.035	0.014	0.011*	0.007*	0.057	0.516	0.150	0.044	0.077	0.014
3	0.020	0.044	0.035	0.014	0.011*	0.008*	0.054	0.534	0.146	0.042	0.037	0.014
4	0.020	0.036	0.035	0.014	0.011*	0.007*	0.047	0.469	0.174	0.039	0.035	0.014
5	0.019	0.036	0.035	0.014	0.011*	0.008*	0.046	0.359	0.178	0.037	0.034	0.014
6	0.018	0.040	0.035	0.014	0.010*	0.007*	0.048	0.305	0.171	0.036	0.027	0.034
7	0.017	0.036	0.035	0.014	0.009*	0.007*	0.063	0.297	0.178	0.035	0.024	0.048
8	0.016	0.035	0.035	0.013	0.009*	0.007*	0.092	0.304	0.166	0.034	0.023	0.090
9	0.016	0.036	0.035	0.013	0.008*	0.007*	0.114	0.283	0.161	0.041	0.023	0.059
10	0.015	0.035	0.035	0.013	0.008*	0.007*	0.157	0.268	0.154	0.034	0.033	0.057
11	0.014	0.035	0.035	0.013	0.008*	0.007*	0.231	0.253	0.147	0.026	0.034	0.078
12	0.014	0.036	0.035	0.013	0.007*	0.007*	0.244	0.226	0.140	0.020	0.043	0.047
13	0.059	0.054	0.035	0.013	0.008*	0.007*	0.294	0.211	0.126	0.019	0.035	0.035
14	0.045	0.039	0.035	0.013	0.007*	0.007*	0.382	0.214	0.117	0.019	0.030	0.034
15	0.038	0.033	0.035	0.013	0.008*	0.007*	0.506	0.195	0.113	0.017	0.026	0.039
16	0.031	0.035	0.035	0.013	0.007*	0.008*	0.609	0.185	0.106	0.016	0.023	0.039
17	0.025	0.035	0.036	0.013	0.008*	0.008*	0.609	0.175	0.098	0.016	0.022	0.038
18	0.022	0.035	0.035	0.014	0.007*	0.010*	0.547	0.168	0.090	0.015	0.021	0.028
19	0.020	0.034	0.032	0.014	0.007*	0.013*	0.450	0.159	0.084	0.015	0.021	0.021
20	0.022	0.034	0.021	0.014	0.008*	0.015*	0.377	0.151	0.079	0.014	0.025	0.016
21	0.021	0.033	0.014	0.014	0.008*	0.016	0.319	0.142	0.074	0.013	0.034	0.013
22	0.021	0.033	0.013	0.015	0.007*	0.016	0.268	0.134	0.071	0.013	0.027	0.011
23	0.021	0.035	0.014	0.015	0.007*	0.016	0.231	0.139	0.068	0.012	0.023	0.009
24	0.021	0.035	0.014	0.015	0.007*	0.020	0.204	0.134	0.064	0.012	0.020	0.008
25	0.031	0.035	0.014	0.014	0.007*	0.021	0.185	0.124	0.063	0.011	0.018	0.006
26	0.036	0.035	0.014	0.014	0.007*	0.020	0.172	0.112	0.061	0.010	0.017	0.006
27	0.024	0.035	0.014	0.014	0.007*	0.020	0.192	0.105	0.057	0.010	0.016	0.005
28	0.024	0.035	0.014	0.013	0.007*	0.020	0.234	0.134	0.054	0.009	0.016	0.005
29	0.024	0.035	0.014	0.012		0.020	0.254	0.165	0.051	0.017	0.015	0.004
30	0.024	0.035	0.014	0.011*		0.020	0.317	0.166	0.049	0.037	0.015	0.004
31	0.024		0.014	0.011*		0.044		0.133		0.013	0.014	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	0.744	1.100	0.839	0.416	0.232	0.396	7.349	7.183	3.372	0.721	0.839	0.801
TOTAL FLOW (cms days)	0.021	0.031	0.024	0.012	0.007	0.011	0.208	0.203	0.095	0.020	0.024	0.023
TOTAL DEPTH (in)	0.219	0.323	0.247	0.122	0.068	0.116	2.160	2.111	0.991	0.212	0.247	0.235
TOTAL DEPTH (cm)	0.555	0.821	0.626	0.311	0.173	0.296	5.485	5.361	2.517	0.538	0.626	0.598

ANNUAL SUMMARY:
Sum of Mean Daily Flow 23.993 cfs = 0.679 cms
Total Depth 7.050 in = 17.907 cm
Maximum Instantaneous Flow 0.640 cfs = 0.018 cms on April 16 at 12.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 300
WATERSHED AREA: 3561 ACRES (1441 HECTARES)

WATER YEAR 1966
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	2.340	2.140	2.237	0.190	0.805	0.779	3.479*	11.122	8.971	3.752	1.452	1.344
2	2.291	2.098	1.794	0.269	0.805	0.779	4.020*	14.143	10.011	3.731	1.393	1.275
3	2.236	2.096	1.819	0.444	0.805	0.779	4.879*	17.954	8.639	3.694	1.361	1.243
4	2.202	3.502	1.969	0.232	0.805	0.779	6.106*	22.636	7.972	3.577	1.311	1.212
5	2.782	1.926	1.973	0.209	0.799	0.779	6.375	27.032	7.349	3.405	1.291	1.179
6	2.469	1.631	1.840	0.413	0.792	0.774	7.152	31.131	6.841	3.262	1.273	1.136
7	2.334	1.524	1.727	0.539	0.780	0.767	8.631	29.524	6.454	3.041	1.263	1.116
8	2.243	1.475	1.688	0.747	0.761	0.767	10.463	27.776	6.173	2.969	1.262	1.103
9	2.207	1.635	1.605	0.652	0.748	0.767	11.734	25.742	7.341	2.937	1.254	1.031
10	2.191	1.848	1.638	0.631	0.742	0.771	12.758	23.329	8.473	3.075	1.237	0.952
11	2.179	2.007	1.600	0.643	0.742	0.779	12.824	21.616	7.822	2.865	1.160	0.947
12	2.157	1.776	1.532	0.680	0.761	0.779	11.777	19.272	7.194	2.705	1.103	1.125
13	2.255	1.729	1.457	0.779	0.779	0.782	10.736	17.631	6.332	2.600	1.108	1.234
14	2.669	2.839	1.419	0.915	0.779	0.796	10.330	16.044	5.944	2.504	1.138	2.235
15	3.893	2.517	3.129	0.948	0.779	0.822	11.805	15.158	5.524	2.445	1.124	3.053
16	2.818	2.038	6.813	0.947	0.779	0.830	17.924	14.699	5.196	2.290	1.070	1.553
17	2.638	2.446	9.475	0.936	0.779	0.830*	15.696	13.182	4.969	2.240	1.048	1.339
18	2.637	2.938	9.936	0.936	0.779	0.840*	13.721	12.628	4.759	2.141	1.062	1.204
19	3.065	2.405	6.957	0.967	0.779	0.910*	12.070	12.507	4.643	2.091	1.042	1.520
20	2.652	2.132	3.270	0.991	0.779	0.990*	10.837	12.880	7.351	2.044	0.999	1.455
21	2.492	2.177	4.182	0.991	0.779	1.071*	9.815	13.424	5.171	1.995	0.981	1.263
22	2.406	2.006	1.474	0.991	0.779	1.209*	9.068	13.399	4.964	1.931	0.972	1.156
23	2.347	1.958	0.394	0.971	0.779	1.362*	9.110	12.290	4.809	1.864	0.928	1.098
24	2.283	1.796	0.241	0.942	0.779	1.518*	10.052	11.614	8.112	1.797	0.901	1.060
25	2.238	1.659	0.183	0.936	0.779	1.684*	11.351	11.371	5.353	1.754	0.881	1.042
26	2.202	1.700	0.137	0.936	0.779	1.859*	10.735	11.122	4.783	1.711	1.394	1.054
27	2.171	1.711	0.121	0.936	0.779	2.037*	9.884	10.897	4.477	1.672	3.062	1.047
28	2.229	1.572	0.180	0.923	0.779	2.221*	9.568	10.426	4.251	1.634	2.012	1.032
29	2.225	2.009	0.236	0.883		2.412*	9.250	10.237	4.080	1.600	1.557	0.999
30	2.186	3.022	0.306	0.853		2.650*	9.505	9.502	3.881	1.569	1.573	0.964
31	2.171		0.377	0.825		3.102*		9.341		1.514	1.465	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	75.211	62.312	71.707	23.255	21.808	37.224	301.654	509.625	187.837	76.406	39.675	37.963
TOTAL FLOW (cms days)	2.130	1.765	2.031	0.659	0.618	1.054	8.543	14.433	5.320	2.164	1.124	1.075
TOTAL DEPTH (in)	0.503	0.416	0.479	0.155	0.146	0.249	2.016	3.406	1.255	0.511	0.265	0.254
TOTAL DEPTH (cm)	1.277	1.058	1.217	0.395	0.370	0.632	5.121	8.652	3.189	1.297	0.674	0.645

ANNUAL SUMMARY:
Sum of Mean Daily Flow 1444.675 cfs = 40.913 cms
Total Depth 9.656 in = 24.527 cm
Maximum Instantaneous Flow 35.780 cfs = 1.013 cms on May 6 at 16.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 300
WATERSHED AREA: 3561 ACRES (1441 HECTARES)

WATER YEAR 1967
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.955	1.631	3.250	1.618	3.303	2.450	2.810	5.603	10.107	2.725	1.022	1.088
2	4.190	1.470	2.593	1.601	3.222	2.411	2.810	5.519	9.611	2.579	0.943	1.068
3	1.957	1.350	2.149	1.586	3.233	2.330	2.971	5.863	9.303	2.507	0.917	1.080
4	1.418	1.273	1.929	1.574	3.728	2.494	3.077	6.093	9.118	2.362	0.916	1.076
5	1.267	1.433	1.764	1.733	3.559	3.832	3.198	7.370	9.150	2.250	0.916	1.063
6	1.202	1.726	1.435	1.589	3.259	4.255	3.113	8.782	12.773	2.129	0.936	1.083
7	1.273	1.464	1.699	1.466	3.157	3.856	3.293	13.711	12.013	2.007	0.926	1.076
8	1.487	1.202	1.563	1.499	3.144	2.343	3.475	20.327	12.577	1.950	0.915	1.114
9	1.314	1.132	2.235	1.519	3.028	2.238	3.604	27.213	10.506	1.894	0.972	1.195
10	1.232	1.419	1.493	1.563	3.020	2.260	3.913	28.753	10.310	1.824	1.044	1.160
11	1.219	1.092	1.527	1.807	2.976	2.244	4.312	25.599	9.593	1.748	1.115	1.273
12	1.875	2.570	1.733	1.670	2.924	2.225	4.634	21.696	9.598	1.656	1.134	1.122
13	1.437	2.541	3.860	1.876	2.872	2.189	4.941	19.061	8.547	1.602	1.131	1.216
14	1.298	2.929	3.817	2.621	2.863	2.184	5.186	18.401	7.007	1.548	1.165	1.203
15	1.282	2.407	2.475	4.690	2.756	2.129	4.884	21.437	6.137	1.475	1.166	1.169
16	1.252	3.016	2.394	5.103	2.807	2.487	4.723	27.991	5.907	1.401	1.139	1.127
17	1.282	2.213	2.068	3.785	2.629	3.508	4.545	34.828	5.602	1.405	1.121	1.110
18	1.218	1.861	2.063	2.961	2.634	2.884	4.807	37.133	5.047	1.359	1.109	1.099
19	1.207	1.761	2.079	2.737	2.601	2.732	5.597	40.668	5.143	1.357	1.106	1.101
20	1.269	1.838	2.336	2.513	2.565	2.648	4.937	27.056	4.567	1.294	1.092	1.093
21	1.417	1.920	1.992	2.397	4.475	2.666	4.691	26.330	4.775	1.258	1.115	1.076
22	1.483	1.606	2.104	2.192	4.072	2.747	4.659	23.959	4.259	1.214	1.106	1.061
23	2.801	1.513	4.814	3.014	2.806	2.994	4.807	23.464	3.913	1.175	1.095	1.061
24	2.390	1.424	4.624	6.861	2.411	3.024	5.075	16.480	3.881	1.147	1.101	1.060
25	2.217	1.169	6.744	4.980	2.411	2.921	5.600	13.463	3.719	1.107	1.102	1.043
26	2.556	1.127	7.759	2.227	2.402	2.913	6.253	11.582	3.495	1.065	1.106	1.033
27	3.496	1.228	7.770	2.273	2.373	2.902*	6.492	10.876	3.357	1.049	1.097	1.029
28	2.091	1.465	5.445	3.571	2.389	2.893*	6.622	10.785	3.189	1.009	1.108	1.018
29	1.708	1.985	2.369	3.448		2.851*	6.244	11.071	3.056	0.994	1.097	1.022
30	3.300	2.531	1.724	3.444		2.810*	5.886	9.975	2.892	0.971	1.091	1.180
31	2.033		1.709	3.460		2.820		9.886		1.072	1.098	

MONTHLY SUMMARY:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	55.125	52.293	91.512	83.377	83.616	85.237	137.158	570.971	209.149	49.131	32.899	33.097
TOTAL FLOW (cms days)	1.561	1.481	2.592	2.361	2.368	2.414	3.884	16.170	5.923	1.391	0.932	0.937
TOTAL DEPTH (in)	0.368	0.350	0.612	0.557	0.559	0.570	0.917	3.816	1.398	0.328	0.220	0.221
TOTAL DEPTH (cm)	0.936	0.888	1.554	1.416	1.420	1.447	2.329	9.694	3.551	0.834	0.559	0.562

ANNUAL SUMMARY:
Sum of Mean Daily Flow 1483.565 cfs = 42.015 cms
Total Depth 9.916 in = 25.187 cm
Maximum Instantaneous Flow 46.860 cfs = 1.327 cms on May 19 at 16.30 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 300
WATERSHED AREA: 3561 ACRES (1441 HECTARES)

WATER YEAR 1968
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	1.199	2.919	2.227	5.704	2.711	0.000	12.767	16.021	18.885	4.347	2.724	2.795
2	1.198	2.173	1.813	4.711	2.333	0.000	13.023	16.438	18.370	4.156	2.712	3.139
3	1.210	1.948	1.672	5.408	2.258	0.000	12.102	17.768	20.726	4.112	2.819	3.009
4	1.204	1.560	1.685	4.913	2.360	0.000	11.648	19.602	16.181	4.034	3.278	2.743
5	1.520	1.068	1.628	4.321	2.311	0.000	12.094	19.738	13.502	3.912	2.966	2.578
6	1.794	2.004	1.584	3.505	2.211	0.000	11.339	18.164	12.099	3.754	2.706	2.499
7	1.668	1.538	1.573	4.396	2.177	0.000	11.230	17.727	11.911	3.612	2.582	2.445
8	1.589	2.150	1.556	4.201	3.160	0.000	10.670	17.812	10.552	3.513	2.493	2.379
9	1.575	2.426	1.583	3.241	5.580	0.000	10.818	18.536	10.678	3.648	2.446	2.333
10	1.519	6.847	1.741	2.255	5.734	0.000	12.101	20.853	9.256	3.530	2.476	2.290
11	3.786	4.777	1.408	3.234	6.368	0.000	13.521	21.568	8.821	3.142	2.470	2.330
12	3.552	3.597	1.708	7.075	9.265	0.000	12.901	23.991	8.551	3.542	2.417	2.545
13	2.871	3.080	4.631	3.638	11.690	0.000	12.548	26.899	8.834	3.279	2.617	2.341
14	3.517	3.761	6.325	2.337	6.181	0.000	12.646	29.001	7.788	3.031	4.165	4.063
15	2.602	2.920	6.928	2.449	5.247	0.000	12.514	28.340	7.071	2.907	5.307	5.641
16	2.085	2.559	6.946	2.284	7.461	0.000	11.898	27.087	6.573	2.787	3.530	7.396
17	1.912	2.373	8.429	2.191	9.968	0.000	11.276	26.738	6.273	2.860	5.257	4.894
18	1.786	2.282	5.955	2.152	25.524	0.000	11.120	27.392	6.124	2.631	4.765	5.571
19	1.886	2.059	5.757	2.109	35.769	0.000	10.713	28.305	6.013	2.615	4.596	4.574
20	1.712	2.009	5.581	2.356	30.591	0.000	9.927	30.116	6.099	2.862	4.167	5.335
21	2.101	1.892	4.569	3.345	19.681	0.000	9.523	30.687	5.419	2.533	4.108	5.470
22	3.238	1.919	3.717	2.785	17.587	0.000	9.198	29.252	6.199	2.368	3.482	5.541
23	4.762	1.938	4.256	2.650	20.238	0.000	8.820	27.252	6.331	2.309	3.173	5.799
24	2.761	1.684	7.358	2.724	16.784	0.000	8.568	25.496	5.338	2.249	2.954	4.947
25	2.799	2.461	28.002	2.716	13.591*	0.000	8.464	26.240	4.973	2.238	2.797	4.395
26	2.471	4.641	48.467	5.471	0.000	0.000	8.624	25.961	4.794	2.159	2.737	3.960
27	5.669	4.660	40.890	16.324	0.267	0.000	8.660	25.045	4.644	2.197	2.825	3.672
28	10.620	3.187	30.084	20.034	0.000	0.000	9.709	24.564	4.564	2.220	6.783	3.546
29	2.860	2.631	19.878	16.338	0.000	0.000	12.497	24.172	5.022	2.225	3.654	3.410
30	3.342	2.366	13.163	14.136		0.000	15.187	22.056	4.723	2.494	3.171	3.246
31	0.000		7.986	5.026		0.000		20.173		2.797	2.961	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	80.804	81.428	279.100	164.028	267.044	0.000	336.103	732.994	266.313	94.064	105.136	114.885
TOTAL FLOW (cms days)	2.288	2.306	7.904	4.645	7.563	0.000	9.518	20.758	7.542	2.664	2.977	3.254
TOTAL DEPTH (in)	0.540	0.544	1.865	1.096	1.785	0.000	2.247	4.899	1.780	0.629	0.703	0.768
TOTAL DEPTH (cm)	1.372	1.382	4.738	2.785	4.534	0.000	5.706	12.444	4.521	1.597	1.785	1.950

ANNUAL SUMMARY:
Sum of Mean Daily Flow 2521.897 cfs = 71.420 cms
Total Depth 16.856 in = 42.815 cm
Maximum Instantaneous Flow 60.730 cfs = 1.720 cms on December 26 at 13.30 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 300
WATERSHED AREA: 3561 ACRES (1441 HECTARES)

WATER YEAR 1969
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	3.132	3.738	-----	-----	-----	-----	-----	20.268	14.642	6.113	2.184	1.399
2	2.990	3.647	-----	-----	-----	-----	-----	19.600	13.512	5.933	2.139	1.388
3	2.732	3.675	-----	-----	-----	-----	-----	18.668	12.496	6.039	2.091	1.401
4	2.514	3.654	-----	-----	-----	-----	-----	19.490	11.665	5.403	2.067	1.432
5	2.573	3.427	-----	-----	-----	-----	-----	20.061	11.460	5.192	2.030	1.474
6	2.588	3.232	-----	-----	-----	-----	-----	22.407	10.626	4.925	2.032	1.416
7	2.305	3.105	-----	-----	-----	-----	-----	26.170	9.915	4.698	1.966	1.386
8	2.392	4.115	-----	-----	-----	-----	-----	29.524	9.084	4.517	1.921	1.360
9	2.453	9.706	-----	-----	-----	-----	-----	32.657	10.724	4.292	1.864	1.325
10	2.395	5.406	-----	-----	-----	-----	-----	35.728	9.268	4.127	1.836	1.379
11	2.461	5.389	-----	-----	-----	-----	-----	38.656	8.059	3.943	1.866	1.608
12	8.130	6.149	-----	-----	-----	-----	-----	40.307	7.616	3.867	1.837	1.499
13	5.563	5.192	-----	-----	-----	-----	-----	41.330	7.076	3.800	1.798	1.420
14	4.310	4.824	-----	-----	-----	-----	-----	41.551	6.688	3.649	1.787	1.369
15	4.438	4.985	-----	-----	-----	-----	-----	40.669	6.327	3.515	1.736	1.373
16	4.021	8.389	-----	-----	-----	-----	-----	37.646	5.934	3.327	1.758	1.359
17	3.616	9.266	-----	-----	-----	-----	16.173	35.979	5.687	3.150	1.725	1.350
18	3.664	4.745	-----	-----	-----	-----	18.293	33.296	5.445	3.048	1.713	1.329
19	3.433	5.227	-----	-----	-----	-----	17.758	36.534	5.279	2.970	1.701	1.779
20	4.738	5.037	-----	-----	-----	-----	18.367	33.761	5.455	2.921	1.660	2.379
21	4.470	4.956	-----	-----	-----	-----	18.394	30.226	5.247	3.074	1.608	2.050
22	4.323	8.467	-----	-----	-----	-----	22.866	28.162	4.985	2.970	1.595	1.701
23	4.703	6.304	-----	-----	-----	-----	29.804	26.221	7.986	2.607	1.562	1.868
24	4.706	5.941	-----	-----	-----	-----	37.912	24.469	12.206	2.560	1.479	2.814
25	4.683	5.705	-----	-----	-----	-----	32.671	22.925	8.250	2.738	1.428	1.820
26	5.120	5.454	-----	-----	-----	-----	28.380	21.089	8.414	2.599	1.471	1.773
27	4.336	5.334	-----	-----	-----	-----	25.439	19.505	8.014	2.561	1.469	1.705
28	4.178	4.905	-----	-----	-----	-----	24.965	18.206	9.519	2.411	1.514	1.768
29	4.126	5.084	-----	-----		-----	24.199	16.313	8.047	2.371	1.522	1.720
30	4.535	4.478	-----	-----		-----	21.787	22.352	6.748	2.343	1.477	2.823
31	4.152		-----	-----		-----		16.658		2.249	1.416	
MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	119.778	159.532	0.000	0.000	0.000	0.000	337.008	870.428	256.374	113.911	54.249	49.465
TOTAL FLOW (cms days)	3.392	4.518	0.000	0.000	0.000	0.000	9.544	24.651	7.261	3.226	1.536	1.401
TOTAL DEPTH (in)	0.801	1.066	0.000	0.000	0.000	0.000	2.253	5.818	1.714	0.761	0.363	0.331
TOTAL DEPTH (cm)	2.034	2.708	0.000	0.000	0.000	0.000	5.721	14.778	4.353	1.934	0.921	0.840

ANNUAL SUMMARY:
Sum of Mean Daily Flow 1960.744 cfs = 55.528 cms
Total Depth 13.106 in = 33.288 cm
Maximum Instantaneous Flow 47.580 cfs = 1.347 cms on May 14 at 17.00 hours

* Indicates some data were estimated during this day.
Summaries exclude missing data.

HORSE CREEK STUDY AREA
WATERSHED: 300
WATERSHED AREA: 3561 ACRES (1441 HECTARES)

WATER YEAR 1970
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	3.357	2.186	7.889	1.973	33.772	2.361	2.433	3.279	36.071	4.343	1.511	-----
2	3.943	2.000	7.892	1.962	24.656	2.500	2.473	4.899	37.474	3.864	1.480	-----
3	3.266	1.903	10.263	1.917	4.491	2.798	2.208	7.228	38.624	3.634	1.463	-----
4	2.587	1.857	6.320	1.818	2.785	2.194	2.191	11.144	38.690	4.380	1.478	-----
5	2.304	2.505	4.624	1.740	2.636	2.059	2.380	18.865	36.150	3.828	1.505	-----
6	2.211	2.447	3.133	1.753	2.616	2.249	2.891	24.724	34.195	3.449	1.487	-----
7	2.185	2.351	2.632	1.965	2.860	2.673	3.253	24.718	32.432	3.325	1.416	-----
8	3.457	2.028	2.041	2.120	2.821	2.290	3.046	22.416	28.960	3.228	1.392	-----
9	3.136	1.911	2.062	2.583	2.688	2.158	4.123	23.426	27.682	3.164	1.365	-----
10	2.867	2.302	1.930	6.398	2.624	3.410	8.601	22.325	25.658	3.130	1.320	-----
11	2.387	2.215	1.870	3.905	2.588	7.455	6.983	19.558	22.073	3.022	1.270	-----
12	1.835	2.640	2.193	3.905	2.691	3.797	6.353	17.646	19.890	2.918	1.221	-----
13	1.849	2.196	2.116	3.905	3.075	2.063	5.851	15.754	18.789	3.232	1.209	-----
14	1.874	2.036	2.308	3.905	2.882	2.587	5.389	15.257	20.027	2.896	1.211	0.557*
15	1.734	2.154	1.985	3.905	2.949	3.042	4.887	18.194	20.135	2.620	1.212	1.486
16	1.924	1.966	1.763	3.905	3.176	2.841	4.500	25.942	17.155	2.375	1.263	1.477
17	1.934	1.859	1.896	3.905	3.510	2.747	4.178	38.754	15.407	2.326	1.350	1.853
18	1.959	2.113	1.938	3.905	3.241	2.869	4.036	44.645	13.944	2.131	0.680*	2.692
19	1.928	2.058	2.161	3.229	3.192	3.081	3.847	49.119	12.791	1.942	-----	4.361
20	1.979	1.910	2.737	4.726	3.270	3.224	3.654	49.914	11.800	1.844	-----	3.362
21	2.014	2.065	5.828	7.189	4.900	2.506	3.510	45.965	10.130	1.221*	-----	3.452
22	1.956	1.788	3.945	12.799	3.007	2.421	3.377	43.793	8.383	-----	-----	4.206
23	1.859	1.763	2.781	14.575	2.881	2.419	3.312	44.443	7.142	1.204*	-----	5.520
24	2.275	1.748	2.384	12.816	2.861	2.792	3.341	45.445	6.286	1.735	-----	3.652
25	2.009	2.687	2.230	7.125	2.954	2.475	3.261	48.216	5.077	1.674	-----	3.121
26	1.864	1.719	2.225	5.350	2.781	2.432	3.165	51.873	4.609	1.688	-----	2.858
27	2.228	2.022	2.196	4.329	2.653	2.431	3.057	46.470	6.668	2.058	-----	2.729
28	2.251	2.101	2.097	4.040	2.483	2.410	2.922	41.642	7.799	2.479	-----	2.517
29	2.006	3.388	2.036	6.389		2.379	2.815	40.296	8.450	2.163	-----	2.382
30	2.047	5.631	2.036	20.991		2.244	2.878	39.373	6.241	2.013	-----	2.271
31	2.177		2.031	41.501		2.545		36.003		1.925	-----	

MONTHLY SUMMARY:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	71.403	67.546	99.536	200.526	137.041	85.450	114.914	941.327	578.731	79.808	23.832	48.496
TOTAL FLOW (cms days)	2.022	1.913	2.819	5.679	3.881	2.420	3.254	26.658	16.390	2.260	0.675	1.373
TOTAL DEPTH (in)	0.477	0.451	0.665	1.340	0.916	0.571	0.768	6.292	3.868	0.533	0.159	0.324
TOTAL DEPTH (cm)	1.212	1.147	1.690	3.404	2.327	1.451	1.951	15.981	9.825	1.355	0.405	0.823

ANNUAL SUMMARY:
Sum of Mean Daily Flow 2448.610 cfs = 69.345 cms
Total Depth 16.366 in = 41.571 cm
Maximum Instantaneous Flow 56.850 cfs = 1.610 cms on May 19 at 18.30 hours

* Indicates some data were estimated during this day.
Summaries exclude missing data.

HORSE CREEK STUDY AREA
WATERSHED: 300
WATERSHED AREA: 3561 ACRES (1441 HECTARES)

WATER YEAR 1971
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	2.178	1.049	1.943	3.210	2.324	3.319	4.787	25.741	38.088	11.366	3.538	3.062
2	2.121	1.098	2.387	3.215	1.898	3.953	5.118	34.947	38.170	10.644	3.539	4.468
3	2.070	1.517	2.788	3.253	1.756	3.060	5.404	48.647	39.110	9.974	3.437	4.049
4	2.019	1.640	2.063	3.253	1.681	3.115	5.736	61.023	44.750	9.304	3.347	2.933
5	3.117	2.372	1.319	3.253	1.536	3.023	6.062	58.187	47.029	8.667	3.507	2.637
6	2.703	2.571	1.741	3.272	1.509	4.223	6.380	50.350	46.246	8.018	3.519	2.425
7	2.417	3.094	3.251	3.275	1.511	3.089	6.733	47.812	35.961	7.402	3.359	2.381
8	2.442	2.714	3.565	3.280	1.504	2.810	7.079	53.920	33.034	6.805	3.147	2.318
9	7.340	3.028	2.944	3.297	1.464	2.810	7.446	58.359	30.548	6.213	3.018	2.220
10	4.675	2.733	2.686	3.301	1.468	2.839	7.790	60.795	29.569	5.709	2.908	2.169
11	3.345	3.200	2.889	3.297	2.384	2.878	8.140	63.506	28.577	5.156	2.880	2.114
12	3.565	4.468	2.246	3.297	3.595	3.040	8.563	68.368	27.574	4.688	2.802	2.075
13	2.979	3.661	2.428	3.285	2.862	3.272	8.641	70.450	26.609	3.801	2.731	2.015
14	2.759	2.614	2.826	3.253	2.889	3.365	9.533	60.248	25.656	3.198	2.645	1.958
15	2.599	2.420	2.745	3.253	3.191	3.416	11.323	53.656	24.670	4.518	2.612	1.922
16	2.462	4.432	3.278	3.253	3.497	3.391	11.124	47.713	23.768	5.303	2.552	1.908
17	2.365	3.932	3.038	3.253	3.915	3.381	11.007	38.874	23.037	5.187	2.467	1.905
18	2.319	3.725	3.111	3.253	3.903	3.327	10.569	32.784	21.801	5.026	2.441	1.929
19	2.479	3.495	2.999	3.240	3.927	3.626	10.754	28.484	20.962	4.907	2.828	1.964
20	2.492	3.077	3.297	3.232	3.904	3.476	11.175	25.683	20.157	4.977	2.306	1.962
21	2.569	1.476	3.421	3.182	3.859	3.278	12.238	24.091	19.237	4.809	2.293	1.928
22	2.825	2.305	3.169	3.124	3.876	3.273	14.003	23.584	18.333	4.575	2.575	1.937
23	2.950	2.038	3.363	3.050	3.758	4.150	15.955	24.090	17.569	4.406	2.821	1.882
24	3.067	2.917	3.730	2.224	3.677	4.574	15.632	25.256	16.676	4.271	2.452	1.873
25	2.650	3.343	3.868	0.900	3.577	3.896	15.581	26.658	15.820	4.163	2.331	1.944
26	2.444	2.739	3.868	0.572	3.746	4.035	15.436	28.554	15.040	4.056	2.239	2.257
27	1.983	3.263	3.882	0.546	3.673	4.116	15.167	30.575	14.236	3.961	2.146	3.372
28	1.416	3.403	3.862	0.493	3.505	3.915	16.025	32.881	13.524	3.857	2.096	2.553
29	1.001	3.192	3.305	0.464		3.952	17.994	34.822	12.752	3.776	2.053	2.450
30	1.036	3.160	3.131	1.173		4.212	20.564	36.455	12.069	3.689	2.020	2.584
31	1.124		3.304	2.666		4.502		37.623		3.594	2.611	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	81.508	84.676	92.444	83.620	80.386	109.312	321.958	1314.135	780.568	176.018	85.217	71.192
TOTAL FLOW (cms days)	2.308	2.398	2.618	2.368	2.277	3.096	9.118	37.216	22.106	4.985	2.413	2.016
TOTAL DEPTH (in)	0.545	0.566	0.618	0.559	0.537	0.731	2.152	8.784	5.217	1.176	0.570	0.476
TOTAL DEPTH (cm)	1.384	1.438	1.569	1.420	1.365	1.856	5.466	22.310	13.252	2.988	1.447	1.209

ANNUAL SUMMARY:
Sum of Mean Daily Flow 3281.034 cfs = 92.919 cms
Total Depth 21.930 in = 55.703 cm
Maximum Instantaneous Flow 77.340 cfs = 2.190 cms on May 12 at 16.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 300
WATERSHED AREA: 3561 ACRES (1441 HECTARES)

WATER YEAR 1972
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	2.480	4.191	2.080	8.446	0.491	0.499	7.673	12.316*	81.923	6.825	3.022	1.897
2	2.409	3.788	2.120	8.589	0.478	0.522*	9.000	12.414*	73.745	6.508	2.966	1.866
3	2.334	2.486	3.386	8.589	0.478	1.627*	9.168*	14.886	67.795	6.345	2.895	1.841
4	2.255	2.222	3.794	8.589	0.478	2.673*	8.450*	18.870	61.617	6.129	2.823	1.860
5	2.241	2.153	3.604	7.691	0.478	3.582*	22.615*	24.210	57.569	5.778	2.735	2.013
6	2.222	2.053	3.033	2.370	0.478	4.889*	11.313*	30.096	53.997	5.947	2.684	2.184
7	2.196	2.062	4.307	2.193	0.478	4.871	12.889*	33.787	48.486	5.799	2.603	2.055
8	2.174	2.189	3.900	3.267	0.478	4.438	13.269*	46.117	47.954	5.191	2.603	2.003
9	2.160	2.230	5.373	4.222	0.468	4.276	12.825*	45.674	41.061	5.350	2.577	1.935
10	2.109	2.655	6.390	4.380	0.457	4.794	12.343*	40.763	39.885	5.152	2.460	1.898
11	2.058	2.976	6.904	4.380	0.453	6.160	11.896*	35.682	33.392	5.231	2.398	1.949
12	2.016	3.813	7.050	4.380	0.446	6.840	11.363*	36.462	27.305	4.762	2.389	3.797
13	2.601	3.772	7.284	4.380	0.446	7.764	10.233*	45.755	22.049	4.348	2.435	2.388
14	3.262	3.217	6.862	3.741	0.446	8.208	9.031*	58.357	20.414	3.970	2.658	2.117
15	2.410	2.926	6.853	6.912	0.453	7.880	8.686*	75.025	19.427	3.702	3.534	2.016
16	2.178	2.769	7.057	10.306	0.465	8.375	8.707*	86.264	19.193	3.680	3.581	1.973
17	2.093	2.614	7.067	10.306	0.488	12.263	8.122*	86.139	17.015	3.682	2.920	1.947
18	2.051	2.431	8.998	6.806	0.499	14.291	7.782*	79.965	16.512	3.734	2.812	1.931
19	3.424	2.366	9.921	3.555	0.499	14.779	7.581*	68.873	14.709	4.161	2.780	2.672
20	3.208	2.453	8.449	3.010	0.500	14.202	7.518*	67.636	14.017	3.896	2.626	3.023
21	2.722	2.675	6.350	1.441	0.497	12.904	7.498*	69.096	14.760	4.931	2.516	2.507
22	2.618	2.729	4.341	0.946	0.485	12.253	7.396*	67.765	13.463	3.811	2.508	2.586
23	2.566	2.496	3.593	0.646	0.478	15.611	7.338*	63.820	13.363	3.585	2.714	2.281
24	2.524	2.887	3.200	0.499	0.472	14.695	7.769*	58.744	12.192	3.578	2.561	2.302
25	2.559	2.778	3.043	0.499	0.476	13.294	7.988*	53.335	11.784	3.400	2.461	2.358
26	2.691	2.368	3.502	0.499	0.499	11.732	8.082*	51.825	10.332	3.236	2.380	2.267
27	2.364	1.887	2.982	0.499	0.497	10.590	9.667*	55.478	8.958	3.184	2.303	2.323
28	3.114	1.910	2.762	0.499	0.504	9.671	12.970*	63.904	8.108	3.165	2.202	2.188
29	2.241	1.917	2.811	0.499	0.499	8.920	14.582*	75.013	7.402	3.102	2.131	2.072
30	1.503	1.911	2.634	0.499		8.374	13.919*	82.224	7.035	3.065	2.214	1.991
31	2.475		5.299	0.499		7.948		85.089		3.054	1.965	
MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	75.256	78.921	154.949	123.132	13.860	258.922	307.671	1645.580	885.461	138.301	81.454	66.239
TOTAL FLOW (cms days)	2.131	2.235	4.388	3.487	0.393	7.333	8.713	46.603	25.076	3.917	2.307	1.876
TOTAL DEPTH (in)	0.503	0.528	1.036	0.823	0.093	1.731	2.056	10.999	5.918	0.924	0.544	0.443
TOTAL DEPTH (cm)	1.278	1.340	2.631	2.090	0.235	4.396	5.223	27.938	15.033	2.348	1.383	1.125

ANNUAL SUMMARY:
Sum of Mean Daily Flow 3829.748 cfs = 108.458 cms
Total Depth 25.598 in = 65.019 cm
Maximum Instantaneous Flow 93.560 cfs = 2.650 cms on June 1 at 16.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 300
WATERSHED AREA: 3561 ACRES (1441 HECTARES)

WATER YEAR 1973
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	1.894	2.123	3.311	9.546	9.449	9.449	9.250	8.281	6.081	3.423	1.421	1.744*
2	1.833	3.363	2.496	9.546	9.449	9.449	9.208	8.737	6.177	3.247	1.382	1.526*
3	1.938	2.600	2.144	9.546	9.449	9.449	9.168	11.609	5.738	3.075	1.394	1.282*
4	2.000	4.240	7.848	9.546	9.449	9.449	9.127	12.354	5.264	2.942	1.397	1.201*
5	1.961	4.018	9.481	9.546	9.449	9.423	9.127	12.440	4.636	2.842	1.364	1.137*
6	1.946	2.666	9.471	9.546	9.449	9.384	9.127	12.749	4.328	2.829	1.350	1.250*
7	1.943	2.406	9.481	9.546	9.449	9.384	9.185	12.669	4.173	2.736	1.322	1.378*
8	1.891	2.501	9.481	9.546	9.449	9.352	9.191	13.353	3.975	2.616	1.289	1.338*
9	2.088	2.299	9.481	9.546	9.449	9.352	9.205	12.092	4.146	2.512	1.264	1.139*
10	3.065	2.254	9.481	9.546	9.449	9.352	9.223	11.230	3.922	2.410	1.289	1.030*
11	2.367	2.198	9.481	9.546	9.449	9.352	4.858	10.659	3.660	2.282	1.264	1.245*
12	2.112	2.158	9.481	9.546	9.449	9.352	6.721	11.265	3.581	2.260	1.236	1.244
13	2.018	2.046	9.481	9.546	9.449	9.352	7.889	12.286	3.567	2.223	1.209	1.206
14	1.935	2.068	9.481	9.546	9.449	9.352	7.501	13.538	12.082	2.160	1.213	1.646
15	1.900	2.127	9.481	9.546	9.449	9.346	6.782	14.648	8.362	2.089	1.218	1.585
16	1.898	2.117	9.481	9.546	9.449	9.320	7.335	15.254	6.202	2.036	1.195	1.395
17	1.878	2.024	9.481	9.546	9.449	9.320	7.622	14.719	9.371	1.926	1.186	1.352
18	1.872	2.041	9.481	9.546	9.449	9.320	6.633	13.691	8.192	1.855	1.189	1.321
19	1.857	1.810	9.481	9.546	9.449	9.325	6.012	12.630	6.979	1.780	1.124	2.342
20	1.859	1.900	9.481	9.546	9.449	9.352	5.543	11.494	6.308	2.148	1.080	3.902
21	1.829	1.750	9.481	9.546	9.449	9.352	5.479	10.361	5.815	6.906	1.081	2.522
22	1.833	8.101	9.481	9.546	9.449	9.352	5.863	9.541	5.454	2.747	1.256	1.795
23	2.022	8.120	9.481	9.546	9.449	9.320	6.314	8.810	5.078	2.263	1.541	1.818
24	1.936	3.945	9.481	9.546	9.449	9.305	6.327	9.070	4.849	2.017	1.223	2.442
25	1.871	3.690	9.481	9.546	9.449	9.320	7.031	9.790	4.714	1.893	1.231*	4.775
26	2.197	9.668	9.481	9.546	9.449	9.352	8.437	8.088	4.619	1.787	1.078*	2.475
27	2.039	5.091	9.481	9.546	9.449	9.352	10.631	7.294	4.257	1.728	1.064*	1.903
28	2.007	4.347	9.481	9.546	9.449	9.352	9.847	6.874	4.089	1.659	1.035*	1.730
29	1.890	3.930	9.481	9.546		9.352	8.969	6.483	3.858	1.598	1.039*	1.628
30	1.836	3.787	9.481	9.498		9.297	8.458	6.173	3.598	1.526	1.153*	1.552
31	1.628		9.481	9.449		9.273		6.492		1.457	1.583*	

MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	61.342	101.388	271.785	295.792	264.569	290.055	236.060	334.676	163.071	74.971	38.670	52.904
TOTAL FLOW (cms days)	1.737	2.871	7.697	8.377	7.493	8.214	6.685	9.478	4.618	2.123	1.095	1.498
TOTAL DEPTH (in)	0.410	0.678	1.817	1.977	1.768	1.939	1.578	2.237	1.090	0.501	0.258	0.354
TOTAL DEPTH (cm)	1.041	1.721	4.614	5.022	4.492	4.924	4.008	5.682	2.768	1.273	0.657	0.898

ANNUAL SUMMARY:
Sum of Mean Daily Flow 2185.284 cfs = 61.887 cms
Total Depth 14.606 in = 37.100 cm
Maximum Instantaneous Flow 28.470 cfs = 0.806 cms on July 21 at 10.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 300
WATERSHED AREA: 3561 ACRES (1441 HECTARES)

WATER YEAR 1974
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	1.534	2.395	2.879	11.423	0.499	2.907	7.162	27.972	40.504	9.647	2.942	1.924
2	1.515	1.622	2.706	5.038	0.879	3.145	6.811	27.566	45.048	9.097	2.903	1.933
3	1.488	1.749	2.566	1.716	0.933	2.768	6.408	26.809	50.243	8.056	3.147	1.965
4	1.494	1.722	2.431	0.718	0.987	2.730	6.054	27.301	61.531	7.141	3.096	1.964
5	1.480	1.911	2.496	0.550	1.045	2.734	5.853	30.351	75.642	7.271	2.941	2.090
6	1.468	2.022	3.912	0.545	1.209	2.680	6.479	35.065	70.735	6.919	3.396	2.179
7	1.664	2.044	3.104	0.542	2.949	2.645	6.180	41.528	63.350	6.775	3.200	2.120
8	1.520	1.781	3.272	0.536	2.918	2.615	6.283	49.222	52.575	6.867	2.972	2.056
9	1.452	3.492	2.567	0.554	2.862	3.449	6.862	49.876	48.200	7.033	2.789	2.110
10	1.462	5.542	2.580	0.545	2.884	2.827	7.163	42.397	45.234	7.477	2.671	3.026
11	1.513	5.657	2.505	0.558	2.897	2.883	7.753	36.864	43.726	8.008	2.565	3.080
12	1.651	6.790	2.535	0.563	2.889	2.941	8.213	32.724	49.835	6.880	2.467	2.448
13	1.593	5.328	2.483	0.564	2.866	2.994	7.973	27.510	50.456	6.172	2.326	2.276
14	2.058	3.708	2.417	0.569	2.831	2.925	8.128	24.450	49.087	5.964	2.243	2.191
15	1.726	3.281	2.434	0.576	2.816	2.956	8.864	22.588	47.071	5.766	2.140	2.111
16	1.574	3.511	3.188	0.576	2.786	3.661	9.807	20.661	40.568	5.205	1.979	2.026
17	1.522	3.193	5.260	0.573	2.790	7.878	10.303	19.172	33.357	4.852	1.836	1.982
18	1.483	2.925	4.306	0.568	2.740	5.984	12.446	18.622	29.455	4.582	1.730	1.953
19	1.436	2.401	3.538	0.565	2.693	5.448	14.829	18.626	27.327	5.045	2.903	1.940
20	1.403	2.504	3.425	0.565	2.629	5.108	14.154	19.645	25.945	6.095	3.902	1.905
21	1.504	2.473	3.495	0.564	2.602	4.880	13.392	21.438	22.606	4.463	2.379	1.894
22	1.445	1.952	3.601	0.564	2.571	4.691	14.026	22.322	20.038	4.144	2.555	1.869
23	1.404	1.844	3.421	0.564	2.521	4.512	19.009	25.500	19.018	4.019	2.464	1.808
24	1.952	1.786	3.211	0.564	2.780	4.361	28.534	29.069	17.189	3.855	2.378	1.781
25	2.453	1.684	2.753	0.564	2.565	4.218	36.192	37.898	15.425	3.745	2.270	1.745
26	1.744	1.696	2.796	0.567	2.610	4.526	37.743	50.337	13.496	3.704	2.180	1.746
27	1.658	1.788	3.882	0.532	2.608	5.154	31.106	57.818	11.939	3.610	2.109	1.819
28	1.856	2.248	6.281	0.458	2.584	5.841	25.785	52.741	10.802	3.476	2.029	1.744
29	2.421	2.774	2.858	0.338		5.824	23.583	46.981	10.078	3.373	1.972	1.705
30	2.176	2.727	12.305	0.463		6.880	24.498	42.652	9.860	3.251	1.945	1.702
31	2.444		15.284	0.391		7.219		40.699		3.093	1.915	

MONTHLY SUMMARY:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	52.093	84.547	120.491	33.413	65.941	129.383	421.590	1026.401	1100.341	175.584	78.341	61.090
TOTAL FLOW (cms days)	1.475	2.394	3.412	0.946	1.867	3.664	11.939	29.068	31.162	4.973	2.219	1.730
TOTAL DEPTH (in)	0.348	0.565	0.805	0.223	0.441	0.865	2.818	6.860	7.355	1.174	0.524	0.408
TOTAL DEPTH (cm)	0.884	1.435	2.046	0.567	1.119	2.197	7.157	17.426	18.681	2.981	1.330	1.037

ANNUAL SUMMARY:
Sum of Mean Daily Flow 3349.214 cfs = 94.850 cms
Total Depth 22.386 in = 56.861 cm
Maximum Instantaneous Flow 79.790 cfs = 2.260 cms on June 5 at 15.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 300
WATERSHED AREA: 3561 ACRES (1441 HECTARES)

WATER YEAR 1975
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	1.694	1.979	2.449	2.655*	2.411	4.055*	2.411*	4.385	58.058	15.628	3.683	3.521*
2	1.685	1.843	2.341	2.458*	2.411	5.116*	2.413*	4.977	64.715	14.615	3.432	3.380*
3	1.685	1.751	1.882	2.226*	2.411	4.779*	2.411*	6.465	66.802	13.986	3.219	3.002*
4	1.690	1.612	1.828	2.036*	2.411	4.277*	2.411*	6.030	57.201	13.255	3.062	2.653*
5	1.700	1.569	1.706	2.036*	2.411	3.780*	2.411*	5.643	57.306	12.335	2.918	2.467*
6	1.691	1.730	1.651	2.036*	2.411	3.290*	2.411*	5.414	64.484	11.504	2.801	2.386*
7	1.753	1.994	1.689	2.036*	2.411	2.878*	2.411*	6.792	64.197	10.726	3.739	2.211*
8	1.710	2.163	1.508	2.036*	2.411	2.810*	2.411*	7.651	55.175	10.054	2.988	2.058*
9	1.757	1.740	1.581	2.036*	2.411	2.810*	2.411*	9.464	50.295	9.334	2.764	1.953*
10	1.753	1.710	1.659	2.036*	2.411	2.810*	2.411*	12.959	44.302	8.594	2.626	1.991*
11	2.151	1.627	1.722	2.036*	2.411	2.810*	2.696*	18.867	45.292	7.733	2.539	2.072*
12	1.928	1.789	1.667	2.036*	2.411	2.662*	2.775*	22.247	47.865	7.417	2.470	2.137*
13	1.845	2.502	1.685	2.463*	2.536*	2.528	2.733*	24.503	44.779	8.874	2.403	2.231*
14	1.787	1.881	1.646	4.382*	2.546*	2.528	2.939*	34.093	42.344	8.011	2.334	2.282*
15	1.785	1.760	1.685	3.722*	2.460*	2.528*	2.977*	48.680	40.138	7.487	2.258	2.350*
16	1.734	1.435	1.925	2.967*	2.411*	2.553*	3.134*	49.912	30.893	6.791	2.287	2.518*
17	1.692	1.746	1.933	4.051	2.411*	2.658*	2.467*	45.340	27.640	5.940	2.843	3.871*
18	1.668	1.905	1.787	38.424*	2.411*	2.803*	2.577*	41.843	26.504	5.483	3.777	2.836*
19	1.670	1.829	1.790	18.071	2.411*	2.720*	2.982*	36.743	25.849	5.286	3.786	3.107*
20	1.672	1.893	1.767	9.909*	2.411*	2.411*	2.548*	30.352	27.178	5.158	3.883	2.991*
21	2.341	2.170	1.932	8.071*	2.411*	2.411*	2.416*	27.682	25.220	4.864	2.934	2.949*
22	2.151	2.325	1.869*	6.375*	2.411*	2.411*	2.764*	25.072	23.774	4.460	3.231	2.764*
23	2.055	1.857	2.072*	5.521	2.607*	2.411*	3.364*	29.747	22.671	4.251	7.072	2.573*
24	2.006	1.977	2.127*	4.805	2.747*	2.411*	4.363*	29.101	22.675	4.104	7.605	2.387*
25	2.046	2.003	2.127*	3.193	2.658*	2.411*	5.026	26.157	21.004	4.024	3.977	2.311*
26	1.961	1.588	2.296	2.716	2.618*	2.411*	4.718	24.339	20.194	3.936	3.436	2.282
27	1.870	1.776	2.310	2.492	2.608*	2.411*	4.685	24.959	18.946	3.825	3.329	2.226
28	2.015	1.458	2.268	2.417	3.718*	2.411*	4.358	26.947	16.258	3.725	3.986*	2.198
29	1.847	2.157	2.332*	2.411		2.411*	4.195	33.289	15.831	4.277	3.718*	2.192
30	1.766	2.419	2.533*	2.411		2.411*	4.309	42.090	15.720	3.918	3.375*	2.159
31	1.712		2.668*	2.411		2.411*		51.114		3.915	3.546*	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	56.817	56.189	60.432	152.471	70.307	89.329	92.137	762.854	1143.308	233.509	106.014	76.056
TOTAL FLOW (cms days)	1.609	1.591	1.711	4.318	1.991	2.530	2.609	21.604	32.378	6.613	3.002	2.154
TOTAL DEPTH (in)	0.380	0.376	0.404	1.019	0.470	0.597	0.616	5.099	7.642	1.561	0.709	0.508
TOTAL DEPTH (cm)	0.965	0.954	1.026	2.589	1.194	1.517	1.564	12.951	19.410	3.964	1.800	1.291

ANNUAL SUMMARY:
Sum of Mean Daily Flow 2899.424 cfs = 82.112 cms
Total Depth 19.380 in = 49.224 cm
Maximum Instantaneous Flow 77.050 cfs = 2.182 cms on June 2 at 19.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 300
WATERSHED AREA: 3561 ACRES (1441 HECTARES)

WATER YEAR 1976
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	2.122	5.516	32.861	10.554	6.366	5.338	4.725	22.234	29.912	11.989	4.297	1.790
2	2.090	6.374	31.738	12.776	6.089	5.329	4.669	27.078	27.839	11.473	5.624	1.636
3	2.036	7.339	17.745	13.019	6.089	5.234	4.716	33.277	26.124	10.847	5.940	1.556
4	3.644	7.284	12.509	11.375	6.157	5.234	5.192	51.186	24.998	10.297	4.723	1.473
5	2.642	7.434	13.908	7.100	6.804	5.234	6.490	50.904	24.338	9.750	3.567	1.425
6	2.822	7.309	12.923	5.543	7.044	5.234	7.669	49.039	23.803	9.196	2.319	3.765
7	4.739	7.077	16.461	4.126	7.050	5.234	8.330	51.094	23.536	8.832	7.659	1.987
8	3.325	6.381	19.813	3.931	7.108	5.206	11.351*	57.795	23.397	8.512	6.798	1.689
9	2.984	5.981	19.684	4.255	7.108	5.170	14.455*	66.577	22.822	8.011	4.448	1.562
10	2.758	5.392	19.247	4.291	7.108	5.134	16.567*	76.071	22.587	7.492	3.626	1.457
11	3.510	5.449	17.739	4.332	7.108	5.130	19.760*	84.857	20.999	7.045	2.960	1.656
12	4.408	5.107	16.320	4.241	7.109	5.130	22.802*	72.472	20.883	11.050	2.910	1.930
13	3.713	4.949	15.038	4.183	7.108	5.130	23.285*	71.158	20.393	7.885	2.733	1.469
14	3.913	5.253	13.754	4.186	7.108	5.130	22.501	76.124	19.034	7.050	2.542	1.342
15	3.633	5.970	12.918	8.013	7.108	5.103	20.309	67.669	17.479	6.470	5.424	1.319
16	3.244	5.506	11.932	8.481	7.108	5.051	18.467	63.597	22.516	5.898	4.243	1.600
17	3.035	4.327	11.113	7.871	7.108	5.031	16.853	60.551	22.553	5.772	2.782	1.792
18	3.337	4.828	11.085	8.025	7.108	4.956	15.380	55.044	20.250	7.122	2.771	1.775
19	3.294	11.397	12.179	7.936	7.108	4.853	14.355	50.384	19.297	6.181	2.505	1.484
20	4.695	18.591	9.700	7.903	7.108	4.751	14.333	47.361	20.198	5.504	2.428	1.346
21	13.079	20.103	8.987	7.731	7.108	4.640	13.635	46.058	20.946	6.086	2.213	1.281
22	8.099	20.990	8.564	7.600	7.059	4.625	13.290	46.295	19.865	4.787	2.668	1.352
23	6.203	12.169	8.454	7.376	7.050	4.625	13.341	46.633	18.394	4.526	3.256	1.619
24	5.284	6.125	8.750	7.237	6.861	4.625	14.579	47.449	17.263	6.334	2.305	1.410
25	5.163	4.410	8.293	7.022	6.449	4.625	14.542	48.958	16.721	5.049	4.274	1.302
26	5.320	4.704	9.262	6.817	5.736	4.625	13.780	45.097	15.797	5.174	3.948	1.231
27	4.680	3.793	8.256	6.738	5.372	4.625	13.375	43.608	14.849	4.637	2.705	1.182
28	4.426	4.088	7.770	6.626	5.338	4.588	13.548	42.066	13.938	4.162	2.361	1.129
29	4.881	4.233	8.145	6.522	5.338	4.559	15.030	37.927	12.831	4.092	2.152	1.085
30	6.130	7.399	7.888	6.277		4.543	17.662	34.898	12.332	4.032	2.185	1.069
31	6.105		6.196	6.199		4.628		34.365		3.898	1.887	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	135.313	225.475	419.227	218.281	194.312	153.320	414.987	1607.827	615.891	219.151	110.253	46.713
TOTAL FLOW (cms days)	3.832	6.385	11.873	6.182	5.503	4.342	11.752	45.534	17.442	6.206	3.122	1.323
TOTAL DEPTH (in)	0.904	1.507	2.802	1.459	1.299	1.025	2.774	10.747	4.117	1.465	0.737	0.312
TOTAL DEPTH (cm)	2.297	3.828	7.117	3.706	3.299	2.603	7.045	27.297	10.456	3.721	1.872	0.793

ANNUAL SUMMARY:
Sum of Mean Daily Flow 4360.750 cfs = 123.496 cms
Total Depth 29.147 in = 74.034 cm
Maximum Instantaneous Flow 89.740 cfs = 2.541 cms on May 11 at 6.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 300
WATERSHED AREA: 3561 ACRES (1441 HECTARES)

WATER YEAR 1977
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	1.037	2.502	4.654	0.680	0.621	0.610	0.542	19.803	8.233	1.382	0.674	1.049
2	2.394	1.744	4.950	0.683	0.624	0.610	0.542	21.033	6.437	2.017	0.651	0.815
3	2.286	1.473	4.665	0.688	0.621	0.610	0.542	16.705	5.350	1.643	0.640	0.750
4	1.486	1.286	4.423	0.693	0.621	0.610	0.538	15.019	5.037	1.907	0.624	0.682
5	1.372	1.117	3.178	0.689	0.621	0.610	0.544	14.089	4.686	1.656	0.604	0.693
6	1.369	1.125	2.226	0.680	0.621	0.610	0.550	14.368	4.398	1.672	0.587	0.693
7	1.214	1.067	2.998	0.680	0.621	0.610	0.539	13.916	4.337	1.129	0.572	0.676
8	1.165	1.092	2.785	0.680	0.621	0.610	0.520	14.893	6.407	1.061	0.551	0.665
9	1.093	1.137	1.909	0.680	0.621	0.610	0.520	14.776	4.421	0.961	0.532	0.677
10	1.140	1.039	1.148	0.680	0.621	0.610	0.499	15.603	3.941	0.881	0.507	0.665
11	2.975	0.981	0.859	0.680	0.621	0.599	0.493	13.990	4.367	0.841	0.493	0.639
12	1.509	0.935*	0.790	0.647	0.621	0.587	0.488	12.996	4.071	0.882	0.478	0.582
13	1.321	1.023*	0.779	0.598	0.958*	0.598	0.478	12.914	4.108	0.915	0.467	0.564
14	1.192	1.119*	0.753	0.598	0.587	0.597	0.482	11.641	3.874	0.958	0.467	0.564
15	1.092	1.223*	0.751	0.598	0.621	0.597	0.478	10.993	3.507	0.961	0.464	0.923
16	1.071	1.441*	0.778	0.598	0.621	0.576	2.898	10.792	3.239	0.919	0.457	1.790
17	1.044	1.426	0.816	0.662*	0.621	0.576	4.775	11.414	2.953	0.914	0.457	1.954
18	0.944	2.718	0.831	2.090*	0.621	0.587	4.596	11.287	2.760	1.667	0.446	1.070
19	0.977	1.419	0.864	1.585*	0.621	0.576	4.557	11.983	2.673	1.420	0.446	0.915
20	0.993	1.175*	1.568	0.658*	0.621	0.576	4.469	11.728	2.899	1.026	0.446	2.248
21	0.977	1.145*	2.394	0.621	0.621	0.576	5.159	11.803	2.641	0.902	0.436	2.087
22	0.949	1.136	3.360	0.621	0.642*	0.564	7.156	11.539	2.470	0.911	0.443	1.608
23	0.915	0.869*	4.009	0.621	0.939*	0.565	11.149	11.846	2.325	0.852	0.452	1.266
24	0.910	1.086*	2.675	0.621	0.610	0.564	15.306	11.650	2.177	1.543	0.830	1.344
25	1.665	1.477	0.787	0.621	0.610	0.564	18.136	10.697	2.042	1.996	1.410	1.381
26	1.625	0.536	0.777	0.621	0.610	0.564	18.896	10.216	1.897	1.742	2.957	1.386
27	1.251	0.849*	0.785	0.621	0.610	0.553	16.150	9.733	1.702	0.938	2.636	1.140*
28	1.125	1.413*	0.700	0.621	0.610	0.553	15.373	9.529	1.574	0.819	1.859	3.167*
29	1.111	2.132*	0.686	0.621		0.553	15.545	8.875	1.403	0.723	1.640	5.429*
30	1.057	3.275	0.683	0.621		0.553	16.902	8.495	1.314	0.701	3.897	5.496*
31	1.031		0.686	0.621		0.542		8.322		0.693	2.062	

MONTHLY SUMMARY:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	40.286	40.956	59.264	22.385	17.984	18.118	168.821	392.647	107.242	36.632	29.184	42.915
TOTAL FLOW (cms days)	1.141	1.160	1.678	0.634	0.509	0.513	4.781	11.120	3.037	1.037	0.826	1.215
TOTAL DEPTH (in)	0.269	0.274	0.396	0.150	0.120	0.121	1.128	2.624	0.717	0.245	0.195	0.287
TOTAL DEPTH (cm)	0.684	0.695	1.006	0.380	0.305	0.308	2.866	6.666	1.821	0.622	0.495	0.729

ANNUAL SUMMARY:

Sum of Mean Daily Flow 976.434 cfs = 27.653 cms
Total Depth 6.526 in = 16.577 cm
Maximum Instantaneous Flow 32.830 cfs = 0.930 cms on May 1 at 24.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 300
WATERSHED AREA: 3561 ACRES (1441 HECTARES)

WATER YEAR 1978
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	4.339	1.842	3.609	4.295*	3.919	4.610	43.581	36.093	27.929	9.631	4.318	2.514
2	4.076	2.952	28.350	3.741*	3.919	5.714	39.395	35.046	28.060	10.074	4.059	2.433
3	3.859	1.915	16.946	3.602*	3.967	6.892	33.303	33.150	28.251	9.621	3.577	2.341
4	1.734	1.790	12.089	3.404*	3.921	5.905	28.417	30.332	28.099	16.074	3.137	2.273
5	1.519	1.968	9.431	3.198*	4.026	4.734	25.645	27.525	28.023	12.160	3.002	2.400
6	1.563	1.980	8.429	3.041*	4.379	4.700	24.975	26.334	27.570	10.893	2.955	2.633
7	2.780	1.795	7.932	2.905	4.168	4.486	23.646	26.370	26.231	14.056	2.900	4.575
8	2.306	1.686	7.146	2.974	4.140	4.849	21.488	26.682	24.651	12.504	2.843	3.579
9	3.197	1.718	6.344	3.111	4.095	5.798	20.385	27.650	23.558	11.222	2.754	2.534
10	2.320	1.719	5.621	2.947	4.070	5.397	20.537	33.854	24.861	10.943	2.661	2.423
11	1.986	1.719	5.565	3.650	4.037	5.443	22.815	36.243	21.929	10.300	2.620	3.739
12	1.964	1.719	5.347	4.368	3.932	5.415	20.711	34.031	19.811	9.733	2.722	5.985
13	2.025	1.803	5.909	4.286	5.128	5.369	19.824	36.494	18.487	9.174	5.724	3.042
14	1.768	1.985	9.155	4.343	5.093	5.230	19.146	37.289	17.325	8.762	4.302	2.807
15	1.685	2.652	9.772	4.367	4.289	5.212	19.958	38.882	16.377	8.904	4.674	2.638
16	1.618	2.116	9.304	4.285	3.941	5.158	20.174	36.541	15.098	8.653	6.696	2.496
17	1.540	1.437	9.026	4.307	2.737	5.320	18.640	34.014	14.190	8.322	6.701	2.455
18	1.515	1.179*	8.491	4.187	2.873	5.889	18.444	32.387	14.022	7.940	4.629	2.663
19	1.472	1.192*	7.707	4.164	3.386	6.818	19.198	33.168	13.357	7.573	3.941	2.535
20	1.430	1.192*	7.260*	4.144	3.901	7.936	19.803	33.496	12.506	7.276	3.763	2.387
21	1.408	1.185*	7.099*	4.112	3.890	9.453	18.672	36.037	12.034	6.911	3.350	2.366
22	1.378	1.177*	6.392*	4.095	3.836	11.534	17.949	36.997	11.595	6.637	7.206	2.301
23	1.370	1.161*	5.919	3.973	3.838	14.177	17.144	33.327	10.872	6.390	4.460	2.255
24	1.360	1.846*	5.506	4.628	4.113	15.682	16.903	31.588	12.866	6.101	3.754	2.213
25	3.566	4.589	5.500	4.069	4.402	15.695	20.043	29.697	16.271	5.670	3.375	2.203
26	3.515	16.493	5.162*	4.066	4.430	16.635	24.437	28.389	11.778	5.255	3.122	2.137
27	1.937	7.459	4.917*	3.933	4.383	19.876	26.433	29.053	10.688	5.084	2.947	2.075
28	1.762	4.918	4.733*	3.949	4.471	24.389	27.503	30.480	10.096	6.788	2.718	2.166
29	1.709	5.114	4.521*	3.951		29.863	27.748	29.018	11.676	5.730	2.574	2.137
30	1.921	4.404	4.305*	3.933		36.317	30.935	27.915	10.359	4.838	2.555	2.072
31	1.862		4.113*	3.950		41.530		27.970		4.539	2.670	
MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	66.482	84.704	241.599	119.976	113.285	346.025	707.850	996.051	548.571	267.756	116.706	80.374
TOTAL FLOW (cms days)	1.883	2.399	6.842	3.398	3.208	9.799	20.046	28.208	15.536	7.583	3.305	2.276
TOTAL DEPTH (in)	0.444	0.566	1.615	0.802	0.757	2.313	4.731	6.658	3.667	1.790	0.780	0.537
TOTAL DEPTH (cm)	1.129	1.438	4.102	2.037	1.923	5.875	12.017	16.910	9.313	4.546	1.981	1.365

ANNUAL SUMMARY:
Sum of Mean Daily Flow 3689.378 cfs = 104.483 cms
Total Depth 24.660 in = 62.636 cm
Maximum Instantaneous Flow 45.800 cfs = 1.297 cms on April 2 at 6.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 300
WATERSHED AREA: 3561 ACRES (1441 HECTARES)

WATER YEAR 1979
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	2.134	1.774	1.702	2.048	2.036	2.317*	5.795*	25.343	18.309	6.283	2.006	2.387
2	2.042	1.468	1.719	2.027	2.036	2.314*	5.364*	27.186	17.185	6.108	1.864	2.097
3	2.024	1.450	1.734	2.033	2.036	2.309*	5.018*	27.296	16.322	5.923	1.827	1.958
4	1.795	1.529	1.761	2.036	2.036	2.305*	4.784*	30.945	15.487	5.832	1.814	1.912
5	1.370	1.335	1.424	2.027	2.036	2.803*	5.332*	37.518	14.687	5.576	1.761	1.843
6	1.359	2.156	1.305	2.036	2.036	4.925*	5.002	34.645	14.778	5.428	1.756	1.745
7	1.374	1.559	1.361	2.036	2.036	5.967*	6.107	28.654	13.403	5.348	1.742	1.693
8	1.379	6.866	1.616	2.036	1.893*	4.809*	5.897	24.578	12.434	5.105	1.713	1.611
9	1.380	2.219	1.851	2.036	1.853*	4.144*	6.584	23.425	11.646	4.842	1.801	1.581
10	1.371	1.325	1.857	2.036	1.984*	3.850*	6.147	22.425	11.009	4.593	1.773	1.913
11	1.374	1.361	1.859	2.036	2.378*	3.727*	5.738	22.576	10.337	4.453	1.714	1.684
12	1.340	1.348	1.870	2.036	3.398*	3.728*	5.356	22.051	9.669	4.425	1.686	1.609
13	1.362	1.352	1.884	2.036	6.331*	3.768*	5.113	23.269	9.126	4.332	1.845	1.597
14	1.356	1.357	1.882	2.036	3.985*	3.773*	4.850	25.759	8.690	4.203	1.935	1.546
15	1.359	1.350	1.857	2.036	3.091*	4.040*	4.891	29.722	8.276	4.047	2.302	1.519
16	1.359	1.330	1.851	2.036	2.824*	4.535*	5.431	33.692	8.002	3.931	1.905	1.489
17	1.357	1.309	1.853	2.036	2.652*	4.551*	8.046	34.019	8.048	3.741	1.750	1.456
18	1.325	1.286	1.875	2.036	2.551*	4.448*	7.895	33.423	8.973	3.563	1.910	1.441
19	1.298	1.266	1.888	2.036	2.500*	4.270*	7.191	32.388	7.959	3.466	1.868	1.377
20	1.277	1.275	1.938	2.036	2.522*	4.216*	6.639	31.719	7.675	3.361	2.092	1.332
21	1.267	1.409	1.967	2.036	2.499*	4.301*	6.453	31.898	14.753	3.228	2.177	1.331
22	1.252	1.642	1.943	2.036	2.463*	4.286*	7.406	34.347	9.371	3.730	1.933	1.281
23	1.248	1.702	1.944	2.036	2.445*	4.336*	8.606	34.767	7.961	3.266	2.600	1.281
24	1.270	1.746	1.998	2.036	2.421*	4.644*	9.645	36.494	7.408	3.118	2.956	1.358
25	1.243	1.799	2.030	2.036	2.404*	5.059*	10.354	32.834	7.015	2.917	2.002	1.371
26	1.365	1.772	2.014	2.036	2.389*	5.051*	11.873	30.693	6.644	2.798	2.010	1.413
27	1.363	1.703	2.019	2.036	2.387*	5.354*	14.857	27.837	6.376	2.618	1.958	1.375
28	1.307	1.696	2.027	2.036	2.340*	6.731*	18.794	26.056	6.126	3.077	1.846	1.325
29	1.303	1.699	2.040	2.036		6.916*	21.915	23.132	6.014	2.811	2.036	1.276
30	1.327	1.693	2.001	2.036		6.611*	24.182	21.106	6.178	2.500	3.224	1.263
31	2.044		2.007	2.036		6.204*		19.696		2.297	3.433	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	44.622	51.772	57.076	63.098	71.559	136.293	251.263	889.493	309.860	126.922	63.240	47.061
TOTAL FLOW (cms days)	1.264	1.466	1.616	1.787	2.027	3.860	7.116	25.190	8.775	3.594	1.791	1.333
TOTAL DEPTH (in)	0.298	0.346	0.381	0.422	0.478	0.911	1.679	5.945	2.071	0.848	0.423	0.315
TOTAL DEPTH (cm)	0.758	0.879	0.969	1.071	1.215	2.314	4.266	15.101	5.261	2.155	1.074	0.799

ANNUAL SUMMARY:
Sum of Mean Daily Flow 2112.258 cfs = 59.819 cms
Total Depth 14.118 in = 35.860 cm
Maximum Instantaneous Flow 40.390 cfs = 1.144 cms on May 4 at 23.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 300
WATERSHED AREA: 3561 ACRES (1441 HECTARES)

WATER YEAR 1980
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	1.281	1.889	1.789	1.750*	1.750*	2.994	2.408	19.985	20.265	9.172	5.339	2.466
2	1.300	1.901	1.853	1.710*	1.777*	2.891	2.472	30.897	21.011	13.419	5.178	3.829
3	1.271	1.882	4.231	1.707*	1.727*	2.810	2.411	26.792	19.194	13.606	5.163	2.783
4	1.223	1.933	5.542	1.703*	1.702*	2.888	2.517	24.599	19.753	12.081	5.060	2.356
5	1.228	2.148	2.739	1.707*	1.702*	2.797	2.711	23.898	16.896	11.250	4.984	2.155
6	1.219	2.017	2.038	1.692*	1.685*	3.144	2.840	22.838	18.392	10.753	4.859	2.089
7	1.226	1.837	2.311	1.688*	1.683*	3.481	2.680	20.618	15.819	10.237	4.727	2.040
8	1.221	1.799	2.143	1.658	1.747*	3.408	2.630	20.044	14.985	10.259	4.611	1.947
9	1.168	1.779	2.116	1.652	1.686*	3.299	3.008	18.047	15.182	12.416	4.496	1.884
10	1.113	1.750	2.255	1.630	1.713*	3.288	3.024	16.122	15.074	10.759	4.417	2.322
11	1.133	1.700	1.949	1.696	1.719*	3.344	3.000	14.589	17.421	9.794	4.314	3.871
12	1.117	1.640	1.886	1.726	1.737*	3.172	3.313	14.143	17.976	9.339	4.149	2.276
13	1.080	1.605	1.844	1.676*	1.863*	3.144	4.257	13.861	16.204	8.968	4.052	3.315
14	1.090	1.546	1.805	1.657*	1.967*	3.094	5.328	12.716	17.206	10.221	3.958	3.192
15	2.046	1.675	1.830	1.679*	2.031*	2.969	6.374	13.600	16.929	8.964	3.917	2.379
16	1.742	1.817	1.762	1.716*	2.124*	2.784	6.691	12.260	15.261	8.426	3.853	2.138
17	2.027	2.337	2.716	1.729*	2.228*	3.079	9.219	11.403	14.799	8.122	3.803	2.043
18	2.405	1.997	2.939	1.707*	2.318*	2.903	12.701	10.845	14.660	7.826	6.514	3.681
19	4.097	1.673	2.358	1.705*	2.395*	2.812	15.219	10.475	13.477	7.581	4.411	3.669
20	2.467	2.427	2.374*	1.715*	2.442*	2.749	18.690	9.767	12.591	7.233	4.150	7.409
21	2.230	4.227	2.395*	1.709*	2.481	2.757	19.456	9.669	11.624	6.916	3.944	5.704
22	2.250	1.904	2.400*	1.727*	2.468	2.710	21.145	10.320	12.150	6.625	3.820	3.764
23	2.911	1.994	2.414*	1.710*	2.471	2.651	22.581	10.283	10.888	6.316	3.748	3.359
24	2.509	1.869	2.382*	1.714*	2.266	2.550	25.711	10.131	10.017	6.101	3.211	3.057
25	2.218	1.864	2.326*	1.713*	2.279	2.686	22.626	13.572	9.390	5.887	2.575	2.807
26	2.191	1.850	2.258*	1.713*	2.271	2.744	22.881	16.364	10.708	5.696	2.184	2.670
27	1.963	1.790	2.171*	1.719*	2.630	2.615	23.696	16.504	10.584	5.539	2.263	2.514
28	1.992	1.753	2.046*	1.720*	3.367	2.647	24.592	17.058	9.046	5.382	2.152	2.344
29	2.148	1.753	1.956*	1.675*	3.228	2.558	23.822	16.447	8.470	5.247	2.048	2.233
30	1.893	1.772	1.875*	1.679*		2.509	20.180	18.307	8.200	5.204	1.973	2.164
31	1.838		1.763*	1.734*		2.504		16.629		5.369	2.738	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	55.594	58.127	72.464	52.717	61.457	89.979	338.179	502.782	434.170	264.707	122.610	88.459
TOTAL FLOW (cms days)	1.574	1.646	2.052	1.493	1.740	2.548	9.577	14.239	12.296	7.496	3.472	2.505
TOTAL DEPTH (in)	0.372	0.389	0.484	0.352	0.411	0.601	2.260	3.361	2.902	1.769	0.820	0.591
TOTAL DEPTH (cm)	0.944	0.987	1.230	0.895	1.043	1.528	5.741	8.536	7.371	4.494	2.082	1.502

ANNUAL SUMMARY:
Sum of Mean Daily Flow 2141.244 cfs = 60.640 cms
Total Depth 14.312 in = 36.353 cm
Maximum Instantaneous Flow 81.830 cfs = 2.317 cms on May 2 at 16.30 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 300
WATERSHED AREA: 3561 ACRES (1441 HECTARES)

WATER YEAR 1981
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	2.071	1.696	2.117	8.610	3.348*	4.568	7.773	23.689	12.861	14.111	5.446	2.613
2	2.059	2.033	2.028	7.983	3.082*	4.486	7.461	21.612	12.454	13.101	5.300	2.670
3	2.015	1.796	2.289	7.248	2.826*	4.394	7.365	19.479	11.966	12.365	5.187	2.208
4	1.944	1.750	2.801	6.620	2.593*	4.330	6.944	17.892	12.512	11.910	5.116	2.070
5	1.897	1.758	2.839	6.220	2.408*	4.350	7.081	16.196	12.243	11.588	5.082	1.970
6	1.857	3.037	2.713	5.816	2.408*	4.541	6.772	14.279	16.106	14.374	4.769	1.938
7	1.822	6.011	2.590	5.360	2.413*	4.748	6.493	13.311	14.579	15.437	4.515	1.888
8	1.795	4.045	2.236	5.574	2.398*	4.966	6.405	12.900	24.362	11.683	4.222	1.805
9	1.752	3.685	2.088	5.032	2.390*	5.163	6.232	12.704	24.828	11.042	3.925	1.756
10	1.752	3.453	1.687	3.872	2.410*	5.230	6.039	12.931	24.524	10.322	3.625	1.719
11	1.739	2.994	1.726	1.998	2.413*	5.227	5.954	13.472	23.985	9.704	3.321	1.720
12	2.037	2.709	2.009	3.421	2.410*	5.334	5.882	12.472	29.650	9.114	3.000	1.703
13	2.098	2.244*	1.947	4.892	2.400*	5.439	5.714	12.056	29.794	8.684	2.720	1.665
14	2.056	6.278*	1.897	6.841	2.788*	5.545	5.966	12.403	31.532	8.274	2.527	1.619
15	1.986	12.855*	2.227	11.867	3.674*	5.679	6.852	13.143	29.103	7.945	2.269	1.598
16	1.947	21.816*	2.408	17.250	10.249	6.062	7.510	12.072	34.176	7.611	2.215	1.591
17	1.875	17.235*	2.405	18.912	8.583	5.790	8.094	11.833	32.889	7.329	2.142	1.556
18	1.822	2.555*	2.413	14.255	6.011	5.689	9.486	11.598	32.504	7.255	2.115	1.545
19	1.769	2.176	2.337	13.514	11.295	5.745	11.214	12.005	34.403	6.998	2.513	2.126
20	1.760	2.060	2.279	9.740	6.939	5.896	12.083	12.102	34.475	6.718	2.326	1.777
21	1.739	2.274	2.587	6.506	5.961	5.758	12.013	20.777	32.085	6.549	2.056	1.813
22	1.712	2.517	6.576	4.414	5.747	6.006	13.190	17.534	29.719	6.337	1.894	1.729
23	1.639	2.582	4.425	6.908	5.631	5.857	16.089	18.317	27.187	6.179	1.814	1.723
24	1.700	1.560	4.442	5.211	5.489	5.871	19.013	17.450	24.035	6.089	1.762	1.752
25	1.811	1.646	14.930	4.001	5.297	7.191	18.290	19.010	21.948	6.511	1.712	2.674
26	2.012	1.710	29.584	4.215	5.024	7.653	17.744	17.030	20.582	6.300	1.704	2.260
27	1.894	1.743	21.122	4.353	4.823	7.599	17.583	15.629	18.992	6.007	1.672	4.708
28	1.731	1.841	15.173	3.793	4.671	7.736	18.521	14.549	17.373	5.864	1.720	3.377
29	1.756	1.987	11.686	3.639		7.897	19.675	13.563	15.964	5.759	1.715	2.231
30	1.752	2.097	11.215	3.598		7.655	21.520	15.425	15.055	5.723	3.871	1.932
31	1.740		9.441	3.510		7.834		14.971		5.631	2.765	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	57.535	122.139	176.215	215.175	125.679	180.235	320.960	472.402	701.885	272.512	95.017	61.734
TOTAL FLOW (cms days)	1.629	3.459	4.990	6.094	3.559	5.104	9.090	13.378	19.877	7.718	2.691	1.748
TOTAL DEPTH (in)	0.385	0.816	1.178	1.438	0.840	1.205	2.145	3.158	4.691	1.821	0.635	0.413
TOTAL DEPTH (cm)	0.977	2.074	2.992	3.653	2.134	3.060	5.449	8.020	11.916	4.627	1.613	1.048

ANNUAL SUMMARY:
Sum of Mean Daily Flow 2801.485 cfs = 79.338 cms
Total Depth 18.725 in = 47.562 cm
Maximum Instantaneous Flow 42.550 cfs = 1.205 cms on June 16 at 19.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 300
WATERSHED AREA: 3561 ACRES (1441 HECTARES)

WATER YEAR 1982
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	1.837	2.060	2.252	3.520	2.424	3.647	3.608	19.795	33.334	18.254	2.568	1.392
2	1.870	1.935	2.877	3.628	2.148	3.662	3.540	25.510	34.752	14.843	3.008	1.180
3	1.782	1.866	2.368	3.711	2.092	3.575	3.514	29.266	36.342	14.146	3.197	1.179
4	1.679	1.834	2.222	3.919	2.097	3.514	3.445	26.647	36.464	12.817	3.533	1.151
5	1.659	1.799	2.374	4.031	2.104	3.443	3.381	22.901	35.009	12.874	3.397	1.138
6	1.702	1.776	3.852	4.049	2.130	3.405	3.368	21.335	34.220	10.345	3.328	1.113
7	1.890	1.730	3.617	4.108	2.147	3.341	3.331	22.650	34.431	10.100	3.261	1.081
8	1.844	1.709	2.766	4.067	2.146	3.266	3.257	21.824	32.865	10.347	3.189	1.058
9	3.227	1.697	2.911	4.104	2.166	3.560	3.235	21.488	32.613	9.908	3.181	1.041
10	4.363	2.015	3.288	4.092	2.164	3.683	3.287	21.357	33.216	7.213	3.114	2.525
11	4.111	1.688	2.703	4.136	2.154	3.921	4.596	22.251	35.229	6.467	3.066	1.503
12	3.019	2.551	2.371	4.182	2.168	3.951	5.490	22.932	37.972	6.080	3.124	1.847
13	2.316	2.368	2.429	4.202	2.185	3.953	5.798	25.856	39.764	8.469	2.983	1.324
14	2.095	2.415	2.447	3.825	2.733	4.050	6.336	31.627	40.183	9.003	2.855	1.185
15	1.991	2.043	2.422	3.391	3.048	4.213	6.236	35.218	38.594	5.896	2.768	1.127
16	1.906	2.175	2.392	2.977	3.312	4.142	6.119	38.201	36.646	6.267	2.588	1.119
17	1.850	3.075	2.059	2.569	3.546	4.043	6.002	41.732	34.022	5.505	2.479	1.071
18	1.757	2.597	2.325	2.393	3.624	3.950	5.772	45.804	30.405	5.334	2.379	1.034
19	1.679	2.156	2.411	2.411	3.622	3.849	5.487	42.120	27.622	5.217	2.302	1.003
20	1.636	2.110	2.406	2.414	3.590	3.709	5.303	41.094	25.437	5.075	2.391	1.057
21	1.538	2.759	2.402	2.421	3.600	3.598	5.353	42.142	23.932	4.954	2.717	1.067
22	1.727	2.829	2.400	2.421	3.677	3.536	5.982	45.335	22.559	4.835	2.222	1.033
23	1.753	2.450	2.405	2.422	4.508	3.501	7.664	48.941	20.441	4.605	2.072	1.002
24	1.801	2.237	2.397	2.458	4.528	3.473	9.963	50.252	18.381	4.390	1.940	0.960
25	1.825	2.338	2.400	2.418	4.471	3.473	11.671	54.038	17.197	4.168	1.892	0.991
26	3.328	3.368	2.414	2.421	4.295	3.576	12.536	56.391	15.336	3.963	1.779	1.614
27	2.606	4.328	2.429	2.419	4.030	3.660	14.258	51.045	14.214	3.744	1.660	2.436
28	2.163	3.998	2.442	2.418	3.818	3.664	16.713	44.616	16.742	3.529	1.523	2.546
29	2.155	2.692	2.426	2.424		3.626	17.624	38.213	17.217	3.308	1.493	1.862
30	2.171	1.383	2.411	2.424		3.621	17.840	34.656	14.719	3.073	2.062	1.468
31	2.115		3.027	2.421		3.641		32.252		2.821	1.651	

MONTHLY SUMMARY:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	67.394	69.982	79.643	98.396	84.528	114.245	210.707	1077.487	869.855	227.548	79.721	40.105
TOTAL FLOW (cms days)	1.909	1.982	2.255	2.787	2.394	3.235	5.967	30.514	24.634	6.444	2.258	1.136
TOTAL DEPTH (in)	0.450	0.468	0.532	0.658	0.565	0.764	1.408	7.202	5.814	1.521	0.533	0.268
TOTAL DEPTH (cm)	1.144	1.188	1.352	1.670	1.435	1.940	3.577	18.293	14.768	3.863	1.353	0.681

ANNUAL SUMMARY:
Sum of Mean Daily Flow 3019.610 cfs = 85.515 cms
Total Depth 20.183 in = 51.265 cm
Maximum Instantaneous Flow 62.440 cfs = 1.768 cms on May 25 at 17.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 300
WATERSHED AREA: 3561 ACRES (1441 HECTARES)

WATER YEAR 1983
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	1.341	1.619	1.270	1.253	2.012	3.407	3.359	11.686	11.113	2.633	1.640	1.340
2	1.328	1.549	1.239	1.244	2.101	4.176	3.315	11.874	10.123	3.570	1.607	2.264
3	2.373	1.482	1.244	1.287	2.140	4.497	3.208	12.122	9.147	3.401	1.501	1.523
4	1.854	1.453	2.441	1.339	2.172	4.947	3.066	12.149	8.115	2.760	1.449	1.358
5	1.720	1.470	1.784	1.456	2.183	5.083	3.352	12.627	7.304	2.423	1.386	1.271
6	1.530	1.817	1.582	6.009	2.211	5.126	3.407	14.081	6.667	2.179	1.327	1.180
7	2.065	1.561	1.481	13.862	2.530	5.302	3.045	14.097	6.167	2.000	1.275	1.102
8	2.074	1.873	1.686	14.449	2.927	5.600	2.912	14.037	5.678	1.860	1.268	1.109
9	1.831	1.553	1.738	11.604	3.341	5.876	2.793	13.425	5.499	1.770	1.471	1.105
10	1.658	1.453	1.683	9.681	4.193	7.050	2.771	12.517	4.930	2.378	1.572	1.489
11	1.601	1.399	1.719	8.103	4.227	8.509	2.623	11.596	4.932	2.305	3.321	3.205
12	1.561	1.454	1.763	7.245	3.900	9.142	2.510	10.690	4.909	2.089	2.320	2.085
13	1.527	1.520	1.824	6.696	2.052	9.733	2.659	10.049	5.019	1.934	1.675	1.916
14	1.442	1.352	1.907	6.172	1.630	9.502	2.788	9.593	4.587	2.807	1.487	1.837
15	1.395	1.695	1.901	5.982	1.571	8.535	2.702	9.587	4.192	2.873	1.577	1.803
16	1.358	1.835	1.857	6.004	1.622	7.396	2.750	9.579	4.158	2.637	1.416	1.779
17	1.313	1.760	2.120	5.216	1.928	6.699	3.315	9.296	3.952	2.392	1.270	1.786
18	1.307	1.555	1.322	3.714	2.572	6.191	4.196	10.165	4.265	2.280	1.123	1.969
19	1.409	1.478	1.280	3.222	2.460	5.545	5.137	11.204	4.200	2.211	1.042	2.462
20	1.525	1.429	1.207	2.047	2.895	5.198	6.110	11.887	3.940	2.247	1.018	2.188
21	1.424	1.383	1.206	1.863	2.663	4.817	7.325	12.816	3.598	2.447	1.000	2.069
22	1.420	1.321	1.202	1.822	2.817	4.437	7.937	13.570	3.399	2.339	1.037	1.935
23	1.412	2.336	1.207	1.808	2.952	4.225	9.997	14.328	3.105	2.089	1.221	1.832
24	1.388	2.349	1.188	1.760	3.149	3.961	14.705	15.036	2.876	2.087	1.166	1.752
25	1.375	2.331	1.178	1.734	3.535	3.797	15.732	15.686	2.691	2.780	1.115	1.681
26	1.704	2.242	1.182	1.548	3.690	3.683	14.504	16.236	2.603	2.545	1.053	1.607
27	1.821	2.171	1.251	1.239	3.553	3.553	13.067	16.478	2.502	2.288	1.007	1.552
28	1.576	1.915	1.237	1.222	3.407	3.409	12.111	16.305	2.491	2.109	0.970	1.526
29	1.725	1.397	1.256	1.300		3.185	11.531	15.488	2.450	1.952	0.942	1.474
30	1.921	1.310	1.261	1.198		3.872	11.406	14.018	2.468	1.802	0.895	1.464
31	1.701		1.265	1.630		3.800		12.582		1.669	0.870	

MONTHLY SUMMARY:

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	49.678	50.062	46.479	133.709	76.433	170.254	184.333	394.802	147.081	72.853	42.020	51.660
TOTAL FLOW (cms days)	1.407	1.418	1.316	3.787	2.165	4.822	5.220	11.181	4.165	2.063	1.190	1.463
TOTAL DEPTH (in)	0.332	0.335	0.311	0.894	0.511	1.138	1.232	2.639	0.983	0.487	0.281	0.345
TOTAL DEPTH (cm)	0.843	0.850	0.789	2.270	1.298	2.890	3.129	6.703	2.497	1.237	0.713	0.877

ANNUAL SUMMARY:

Sum of Mean Daily Flow 1419.366 cfs = 40.196 cms
Total Depth 9.487 in = 24.097 cm
Maximum Instantaneous Flow 16.490 cfs = 0.467 cms on May 26 at 21.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 300
WATERSHED AREA: 3561 ACRES (1441 HECTARES)

WATER YEAR 1984
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	1.524	1.423	1.125	1.629	2.309	1.518	3.709	12.338	61.527	9.918	2.598	1.983
2	1.526	1.437	1.141	1.842	2.012	1.438	3.592	13.664	51.007	9.056	2.504	1.600
3	1.522	1.377	1.144	2.083	1.808	1.417	3.493	13.080	45.215	8.382	2.366	1.506
4	1.473	1.325	1.102	18.631	1.742	1.378	3.686	12.601	44.588	7.811	2.224	1.422
5	1.464	1.300	1.001	20.535	1.729	1.409	4.722	12.493	44.872	7.179	2.225	1.603
6	1.433	1.276	0.905	20.263	1.696	1.401	5.366	11.915	46.158	6.679	2.381	2.849
7	1.417	1.305	0.882	10.851	1.641	1.421	4.954	11.932	50.882	6.392	2.174	2.310
8	1.386	1.294	0.867	4.675	1.645	1.413	5.823	12.958	47.270	6.007	2.012	3.073
9	1.384	1.248	0.868	4.312	1.624	1.490	5.675	18.877	42.115	5.678	1.948	2.444
10	1.500	1.182	0.896	4.398	1.598	1.666	5.612	18.797	39.072	5.297	1.894	2.162
11	1.512	1.239	0.950	3.759	1.571	1.937	5.249	20.461	43.020	4.905	1.898	2.045
12	1.516	1.605	0.939	2.011	1.596	1.847	5.110	27.391	39.520	4.440	1.902	1.970
13	1.441	1.593	0.898	1.708	1.689	1.940	5.014	34.989	37.659	4.069	1.860	1.890
14	1.417	1.445	0.849	1.522	1.766	2.776	5.892	49.719	35.446	3.765	1.830	1.815
15	1.369	1.318	0.836	1.503	1.749	2.685	9.241	51.487	34.823	3.510	1.791	1.782
16	1.321	1.271	0.852	1.528	1.744	2.918	15.831	43.310	34.653	3.266	1.771	1.754
17	1.275	1.282	0.842	1.530	1.747	2.959	25.775	36.815	29.646	3.061	2.049	1.729
18	1.360	1.279	0.814	1.551	1.737	2.791	29.558	35.969	26.888	2.929	2.058	1.690
19	1.373	1.265	0.801	1.554	1.759	3.211	28.556	38.375	24.292	2.862	1.743	1.665
20	1.356	1.196	0.805	1.573	1.804	6.533	24.112	48.597	23.390	2.720	1.646	4.787
21	1.335	1.065	0.768	1.582	1.413	7.018	20.798	48.897	27.115	2.644	1.598	3.385
22	1.307	1.055	0.770	1.601	1.434	6.420	19.880	45.029	21.219	2.591	1.551	2.705
23	1.456	1.100	0.795	1.623	1.462	6.988	21.088	54.758	18.784	2.507	1.557	3.001
24	1.520	1.077	0.801	2.035	1.469	5.882	19.352	48.648	17.282	2.437	1.530	2.745
25	1.524	1.062	0.814	2.439	1.501	5.196	18.084	43.318	18.042	2.360	1.513	2.508
26	1.552	1.053	0.816	2.439	1.532	4.842	16.549	45.480	15.156	3.083	1.480	2.545
27	1.530	0.988	0.876	2.463	1.541	4.466	14.944	47.027	13.977	2.868	1.408	2.462
28	1.507	0.954	0.994	2.473	1.532	4.223	13.770	49.618	12.640	5.871	1.456	2.225
29	1.503	0.968	1.115	2.479	1.540	3.991	12.710	57.718	11.587	3.825	1.354	2.130
30	1.495	1.102	1.256	2.471		3.859	12.135	75.566	10.912	3.322	1.768	2.081
31	1.482		1.451	2.431		3.797		71.314		2.772	2.702	

MONTHLY SUMMARY:	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TOTAL FLOW (cfs days)	44.774	37.082	28.971	131.495	48.389	99.829	370.281	1113.138	968.756	142.207	58.792	67.864
TOTAL FLOW (cms days)	1.268	1.050	0.820	3.724	1.370	2.827	10.486	31.524	27.435	4.027	1.665	1.922
TOTAL DEPTH (in)	0.299	0.248	0.194	0.879	0.323	0.667	2.475	7.440	6.475	0.951	0.393	0.454
TOTAL DEPTH (cm)	0.760	0.630	0.492	2.232	0.822	1.695	6.286	18.898	16.447	2.414	0.998	1.152

ANNUAL SUMMARY:
Sum of Mean Daily Flow 3111.577 cfs = 88.120 cms
Total Depth 20.798 in = 52.826 cm
Maximum Instantaneous Flow 87.930 cfs = 2.490 cms on May 30 at 17.00 hours

* Indicates some data were estimated during this day.

HORSE CREEK STUDY AREA
WATERSHED: 300
WATERSHED AREA: 3561 ACRES (1441 HECTARES)

WATER YEAR 1985
MEAN DAILY FLOW IN CUBIC FEET PER SECOND

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	2.055	1.728	1.949	2.969	2.555	2.293	2.342*	17.655	15.639	5.050	3.739	1.309
2	2.062	2.766	1.931	2.980	2.533	2.291	2.521*	21.786	13.728	4.870	6.551	1.301
3	2.039	3.482	1.764	3.200	2.566	2.287	2.712*	23.029	12.578	4.711	3.216	1.301
4	1.924	2.706	1.157	3.466	2.545	2.271	2.876*	19.448	14.481	4.595	2.525	1.313
5	2.009	2.440	2.670	3.681	2.542	2.272	2.844	17.340	16.232	4.479	2.581	1.316
6	1.910	2.980	9.912	3.755	2.344	2.250	3.107	16.936	15.180	4.341	2.183	2.761
7	1.856	3.076	7.836	3.536	2.326	2.246	3.734	16.845	14.722	3.953	2.078	3.200
8	1.787	2.620	3.683	2.984	2.299	2.247	5.361	16.122	13.806	3.486	2.137	6.028
9	1.754	2.483	3.740	2.747	2.298	2.301	6.889	16.227	12.741	3.262	2.068	5.803
10	1.716	2.352	3.662	2.603	2.296	2.287	8.502	17.076	11.993	3.612	2.443	4.680
11	2.214	2.318	3.001	2.452	2.296	2.339	11.255	16.019	11.300	3.031	2.939	4.914
12	2.220	2.524	2.710	2.400	2.288	2.331	10.756	14.262	10.705	2.845	3.087	7.052
13	2.927	2.736	2.475	2.458	2.266	2.301	12.095	13.942	10.281	2.738	2.631	3.830
14	2.357	3.682	2.467	2.572	2.268	2.283	15.257	14.745	9.955	2.660	2.262	3.212
15	2.244	2.001	2.745	3.554	2.276	2.258	18.186	15.157	9.426	2.577	2.120	3.824
16	2.090	2.377	2.666	3.749	2.345	2.258	19.926	15.908	8.910	2.464	2.034	3.184
17	2.016	2.930	2.540	3.837	2.320	2.255	19.459	16.517	8.467	2.422	1.970	4.485
18	2.055	1.973	2.473	4.242	2.306	2.277	16.877	16.817	8.064	2.366	1.906	3.425
19	2.018	2.242	2.314	4.465	2.294	2.263	14.047	16.518	7.703	2.283	1.916	3.102
20	1.875	2.216	2.496	4.386	2.294	2.260	11.629	15.933	7.393	2.200	1.959	2.877
21	1.927	2.183	2.906	4.109	2.279	2.255	9.880	15.305	7.060	2.147	3.178	2.766
22	1.792	2.284	4.500	2.338	2.250	2.257	8.643	14.209	6.791	2.082	2.456	2.666
23	1.805	2.196	4.351	2.038	2.255	2.230	7.867	14.062	6.512	2.048	2.173	2.445
24	2.009	1.950	3.994	2.027	2.246	2.219	6.978	13.936	6.273	2.027	1.961	2.233
25	2.531	2.288	4.004	2.163	2.247	2.230	6.234	13.093	6.172	1.976	1.812	2.164
26	3.180	2.142	3.759	2.227	2.249	2.235	5.966	11.891	6.007	1.886	1.715	2.117
27	2.412	2.121	3.247	2.263	2.299	2.225	7.406	11.019	5.777	1.817	1.634	2.086
28	2.345	2.017	2.912	2.402	2.306	2.217	8.762	12.513	5.569	1.786	1.519	2.024
29	2.241	1.701	2.729	2.519		2.233	12.297	15.788	5.402	1.858	1.446	2.071
30	2.158	2.253	2.640	2.573		2.242	13.907	15.940	5.176	2.060	1.395	2.157
31	1.883		2.461	2.576		2.227		13.047		2.181	1.326	
MONTHLY SUMMARY:												
TOTAL FLOW (cfs days)	65.410	72.765	101.693	93.270	65.386	70.137	278.313	489.084	294.045	89.813	72.956	91.646
TOTAL FLOW (cms days)	1.852	2.061	2.880	2.641	1.852	1.986	7.882	13.851	8.327	2.544	2.066	2.595
TOTAL DEPTH (in)	0.437	0.486	0.680	0.623	0.437	0.469	1.860	3.269	1.965	0.600	0.488	0.613
TOTAL DEPTH (cm)	1.110	1.235	1.726	1.583	1.110	1.191	4.725	8.303	4.992	1.525	1.239	1.556

ANNUAL SUMMARY:
Sum of Mean Daily Flow 1784.518 cfs = 50.538 cms
Total Depth 11.928 in = 30.296 cm
Maximum Instantaneous Flow 26.820 cfs = 0.760 cms on June 1 at 18.00 hours

* Indicates some data were estimated during this day.

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Mosko, Timothy L.; Jeffers, Bud L.; King, John G.; Megahan, Walter F. 1990. Streamflow data for undisturbed forested watershed in central Idaho. Gen. Tech. Rep. INT-272. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 334 p.

This is a summary of daily streamflows from 29 undisturbed, forested watersheds. The watersheds are at Silver Creek, Tailholt Creek, and Horse Creek in the headwaters of the Idaho batholith region. Data sets span up to 20 years. Descriptions of each watershed are included. The data provide calibration for accurately quantifying the effects of subsequent timber harvest activities.

KEYWORDS: surface waters, Idaho batholith, runoff, hydrologic data, water yields

INTERMOUNTAIN RESEARCH STATION

The Intermountain Research Station provides scientific knowledge and technology to improve management, protection, and use of the forests and rangelands of the Intermountain West. Research is designed to meet the needs of National Forest managers, Federal and State agencies, industry, academic institutions, public and private organizations, and individuals. Results of research are made available through publications, symposia, workshops, training sessions, and personal contacts.

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